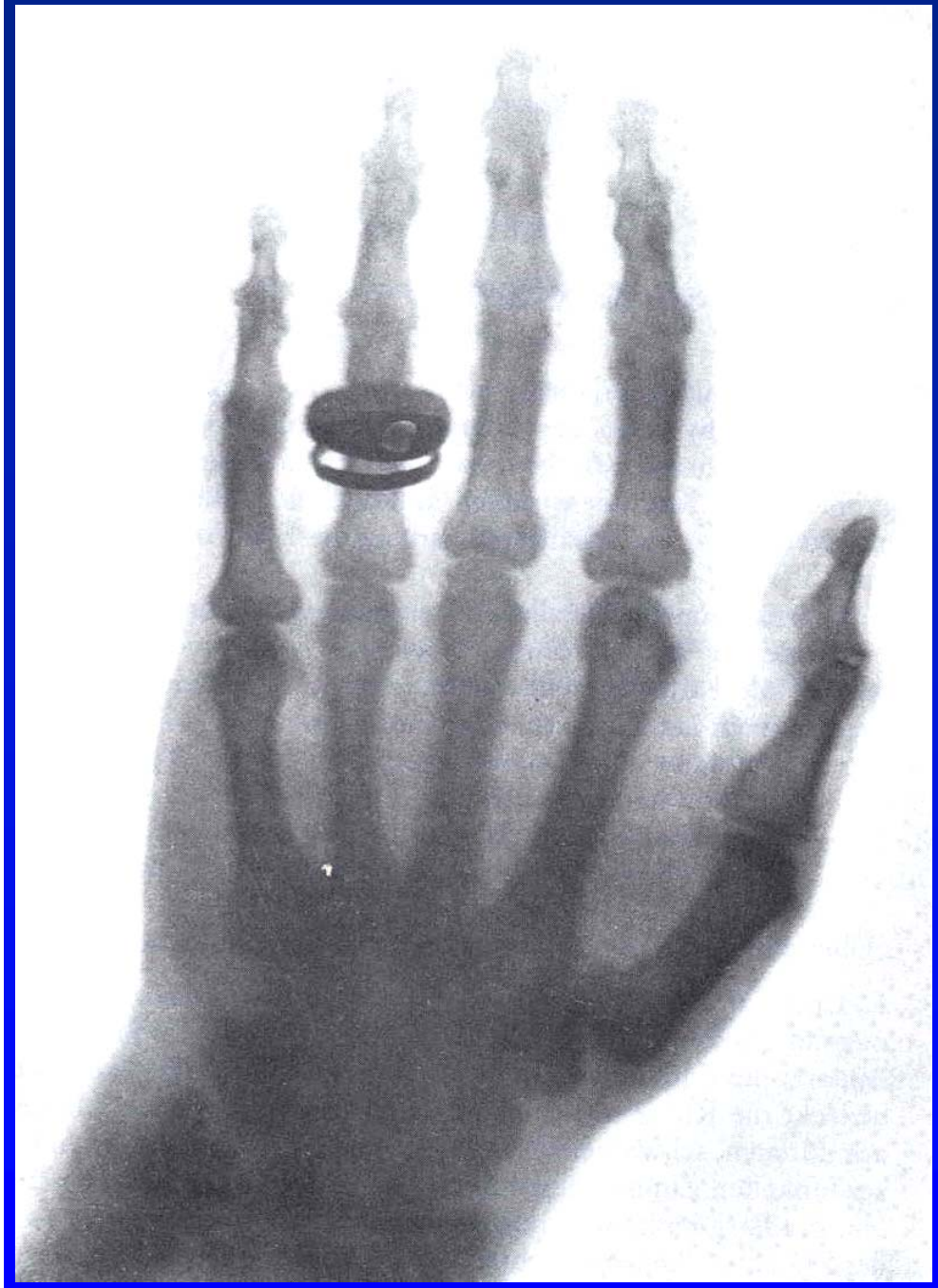
Zentrum für Strahlenschutz und Radioökologie
Leibniz Universität Hannover

Biological Effects of Ionizing Radiation and the Radiation Exposure of Man

R. Michel

Contents

- a historical introduction
- the natural and man-made radiation exposure of man
- biological effects of ionizing radiation
- radiation and risk



X-ray picture of the hand of Geheimrat von Kolliker at Würzburg, taken on 23.01.1896 by W.C. Röntgen

W.C. Röntgen received the 1st Nobel Prize for Physics in 1901.

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X-ray investigation in 1906

Secondary Erythema of a Nail
ca. 15 Gy, 4 weeks after irradiation during changing a sample of a X-ray-scattering device

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Radiation Damage by X-Rays ca. 100 Gy

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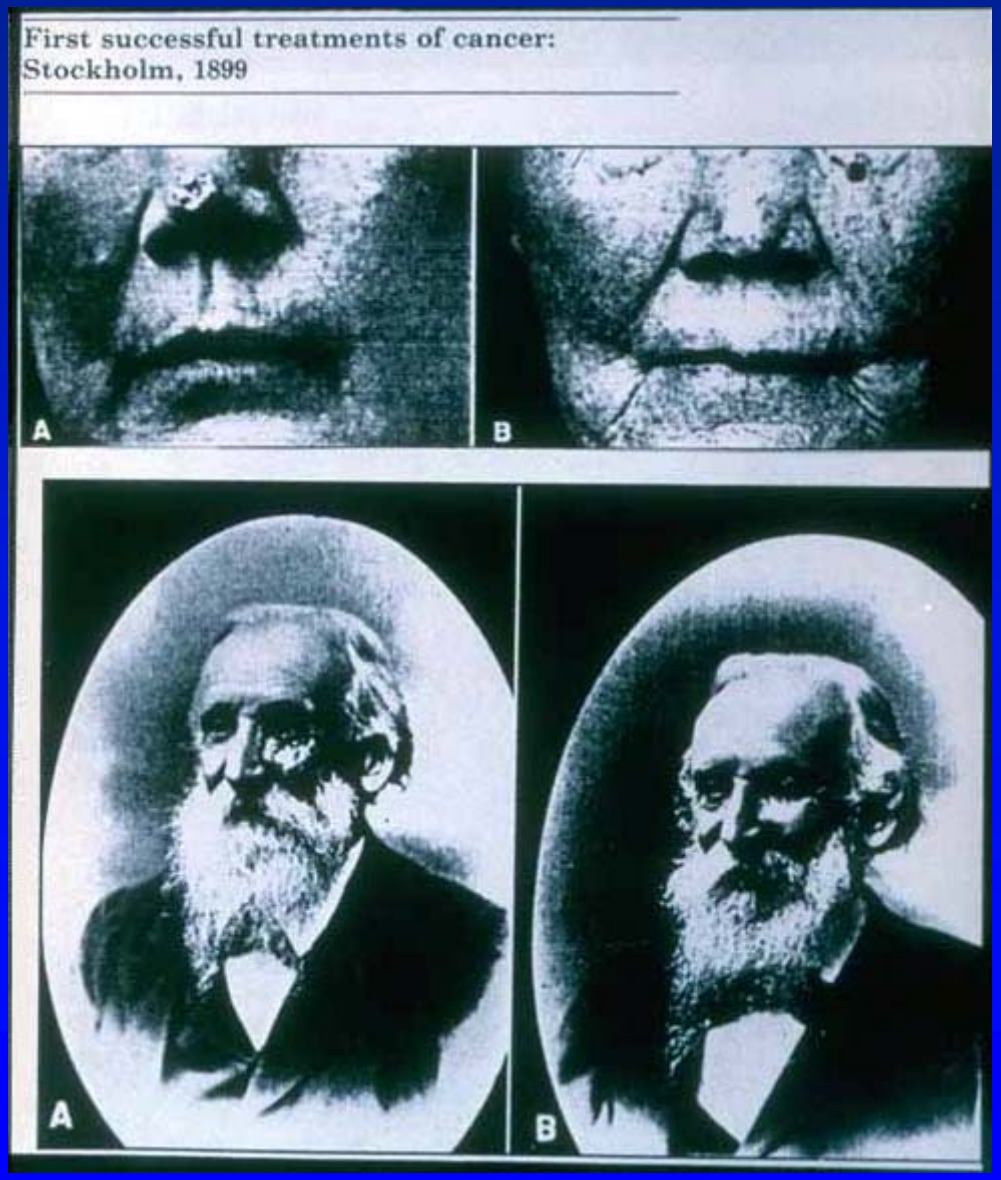
First cancer therapy with X-rays in the year 1899



Thor Stenbeck treated a carcinoma of the nose of a 49-years old women. 100 irradiations in the course of 9 months. The patient survived with good health 30 years.

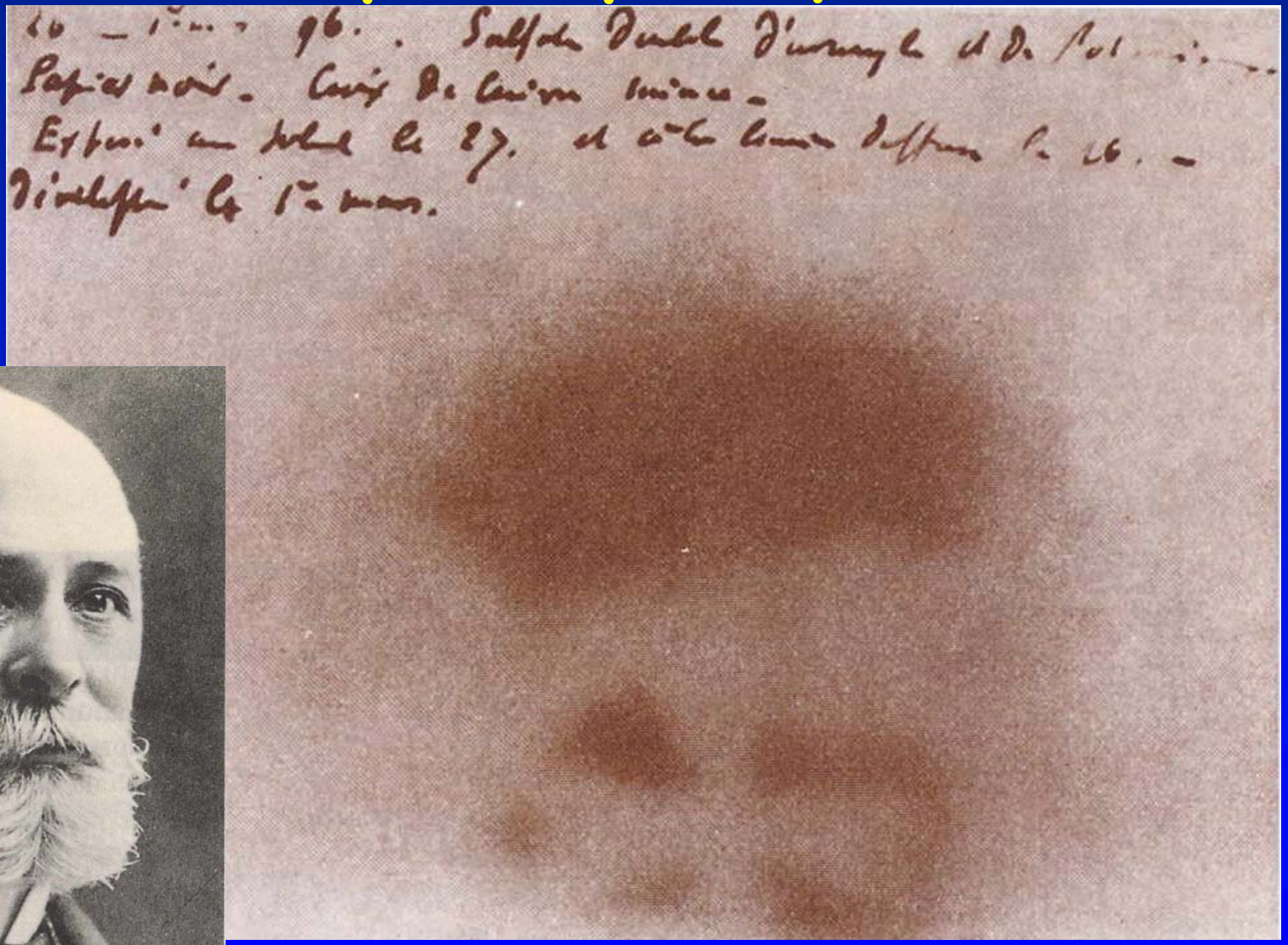
Tage Sjörgen cured a carcinoma by 50 irradiations during 30 months.

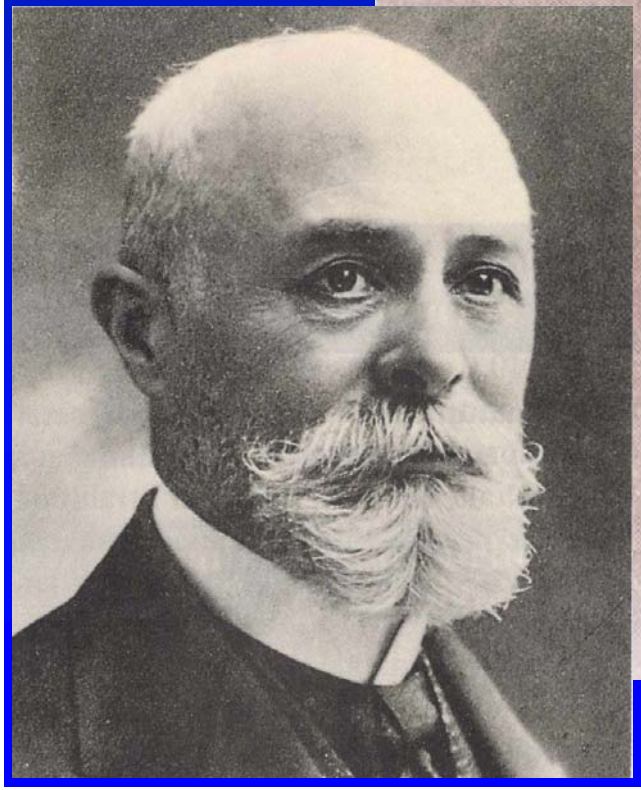
X-ray carcinoma

1896 X-ray lesions of the skin

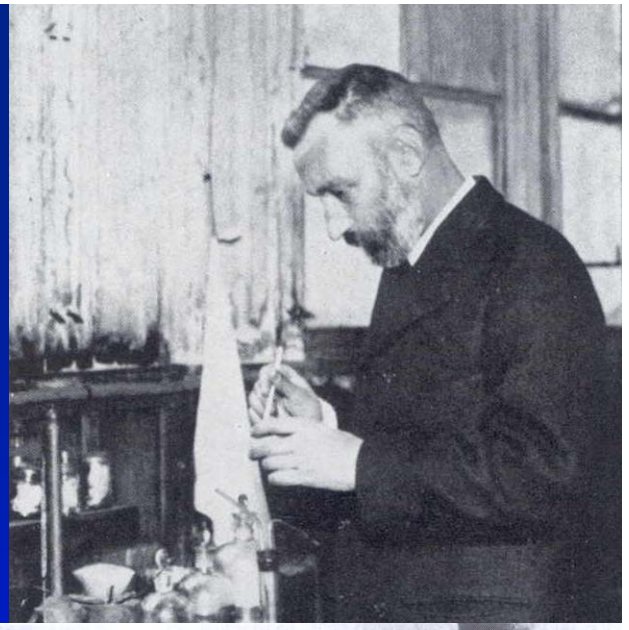
1902 Skin carcinoma as a consequence of X-ray dermatitis

Discovery of Radioactivity in 1896 by Henry Becquerel





The Curies in the Lab



Discovery of the radioactive elements Thorium, Polonium, Radium,

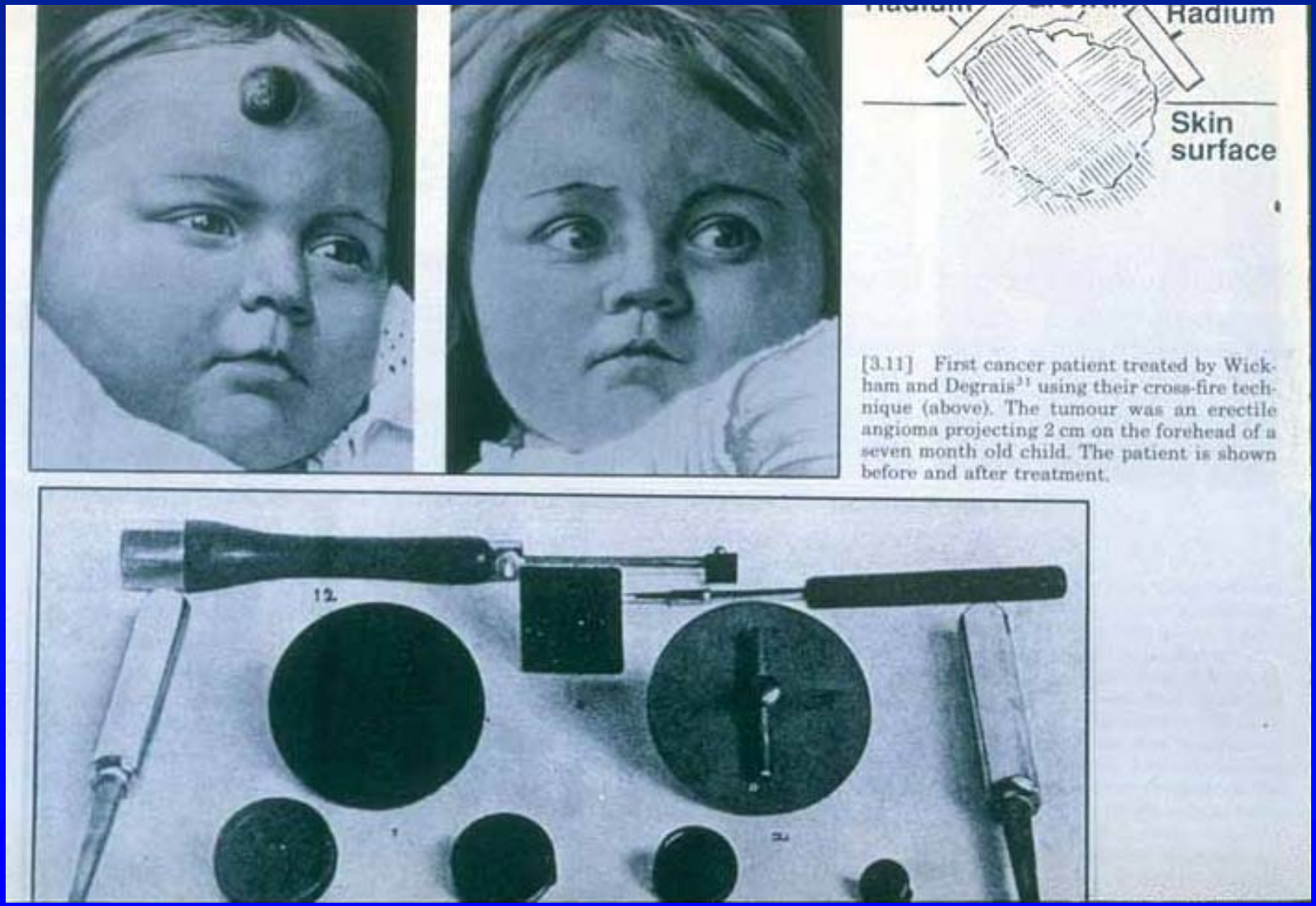
and of a new chemistry: radiochemistry

Pierre Curie's experiment on himself

After reports by Walkhoff and Giesel (1900) on physiological effects of radium, P. Curie made an experiment on himself by irradiating his arm with radium rays. On July 3rd, 1901, he reports to the Academie Francaise:

„The skin has reddened on a surface of 6 cm^2; it looks like a burn, but the skin does not or just weekly cause pain. After some days the erythema became stronger without increasing its size: at the 20th day it became first a crust and afterwards a wound which was treated with dressings; at the 22th day the skin started to heal from the sides to the center and 52 days after the irradiation only a wound with an area of 1 cm^2 remained which had a grayish color indicating a deeper wound …"

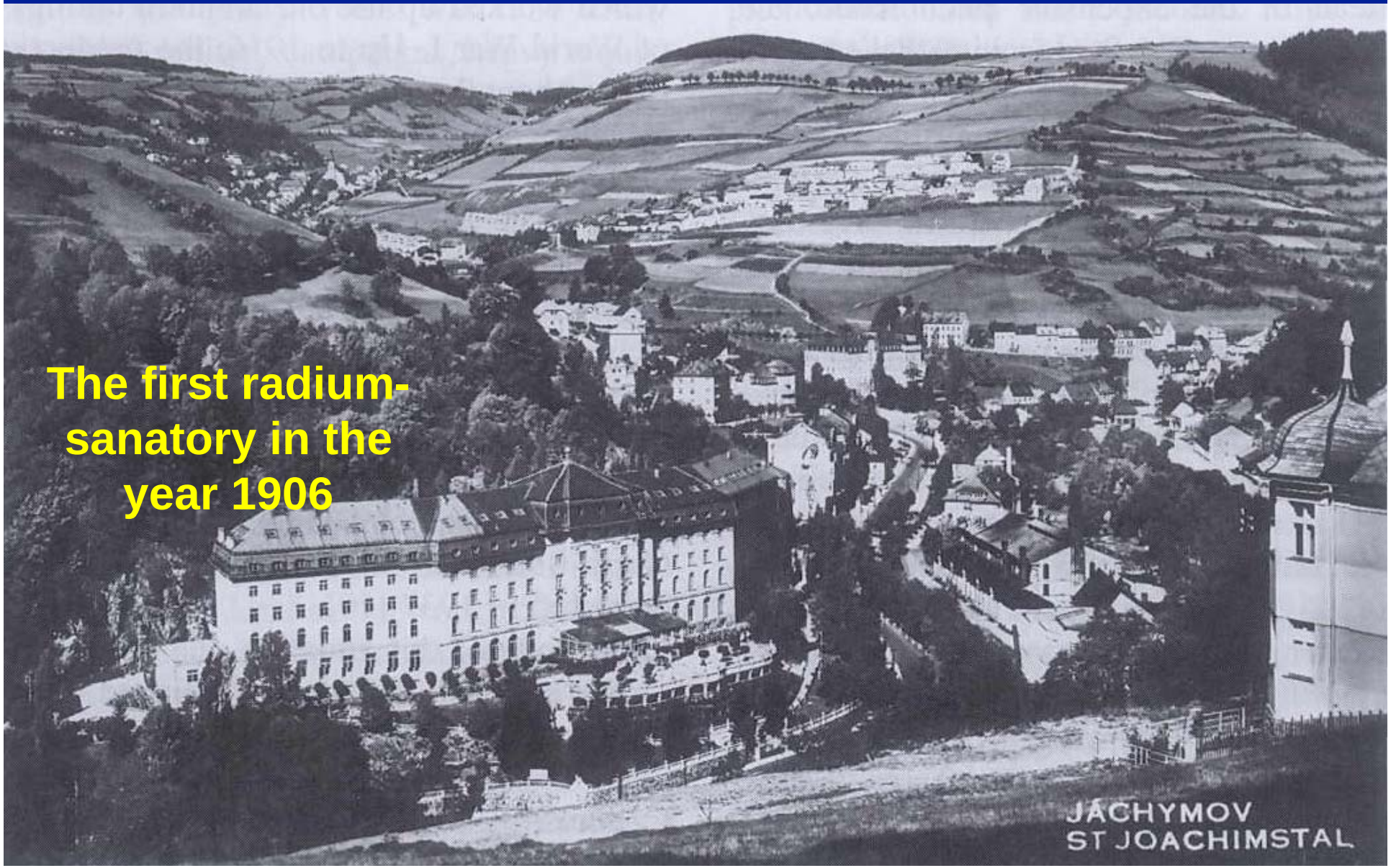
First Cancer Treatment with Radium in the Year 1907 by Louis Wickham and Paul Desgrais



[3.11] First cancer patient treated by Wickham and Degrais[31] using their cross-fire technique (above). The tumour was an erectile angioma projecting 2 cm on the forehead of a seven month old child. The patient is shown before and after treatment.

The first radium-sanatory in the year 1906 R. Michel, ZSR, Leibniz Universität Hannover

St. Joachimsthal ca. 1920, left Radium Palace, right factory for uranium colors and radium



Production of a radium preparation

by sealing of $RaCl_2$ in a glass ampoule in the year 1912

Archiv Horák

Gesundheit und Jugendfrische bis ins hohe Alter!

Auf vielfachen Wunsch veranstaltet die

Radiumchema St. Joachimsthal,

die unter Beteiligung des Prager Gesundheitsministerium gegründet wurde, und deren Präparate mit dem Staatswappen der Č. S. R. ausgezeichnet sind,

einen einmaligen, hochinteressanten **Lichtbildervortrag:**

Heilung durch Radium.

Warum gerade Radium?
Welche Krankheiten können mit Radium geheilt werden?
Kann man sich vor Krebskrankheiten schützen?

Niemand versäume diesen Aufklärungsvortrag!
Wichtige Lebensfragen für jedermann!

Was muß man vor Anschaffung eines Radiumpräparates wissen, wenn man keine Enttäuschung erleben will?

Nicht zu verwechseln mit ähnlichen hier gehaltenen Vorträgen!

Erscheinen Sie rechtzeitig, da in vielen Städten die Vorträge überfüllt waren!

Nur für Erwachsene!

Nur Aufklärung, kein Verkauf!

Bitte wenden!

Radiumchema AG, 22.11.1932

Radium bread and Radium beer

Advertisements in local newspapers from Joachimsthal from the years 1924 und 1930

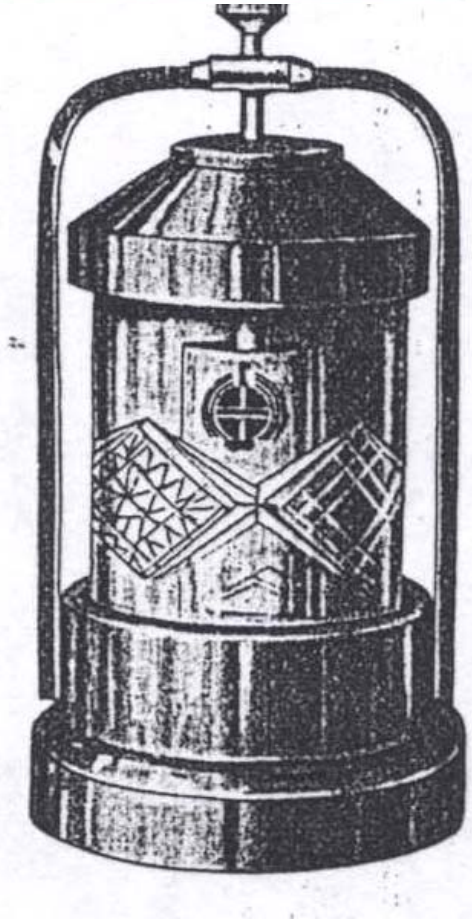

RADIUM-
WASSERZWIEBACK
Grossbäckerei-
Hippmann-Bloch
St. Joachimstal.
PRÄMIERT MIT DER GOLDENEN AUSSTELLUNGSMEDAILLE
Unter Zusatz von St. Joachimstaler
Radiumwasser.
Prämiert mit der goldenen Ausstellungsmedaille.
„Man achte auf Firma u. ges. gesch. Packung".

Radium-Nährsalz »Truw«.

Radium-Nährsalz »Truw« enthält neben den im Körperhaushalt notwendigen Mineralstoffen und Spurenelementen *radioaktive Stoffe* in körperverträglicher Form und unterschwelliger Stärke.

Radium-Nährsalz »Truw« dient zur Verbesserung der Blutbeschaffenheit, zum Ausgleich des Mineralstoffwechsels bei Mangelzuständen und Bilanzstörungen und zur Behebung und Anregung der Zelltätigkeit. Es wirkt fermentaktivierend und die Blutbildung fördernd.

Radium-Nährsalz »Truw« ist angezeigt bei allen *Erschöpfungszuständen nervöser* und *körperlicher Art*, nach *konsumierenden Krankheiten*, in der *Rekonvaleszenz*, bei *Ermüdung, Erschlaffung, Blutarmut*, zur Hebung des Kräftezustandes und des Allgemeinbefindens.



LA CREMA ATOMICA

RADIUM CREMA

SENSAZIONALE NOVITÀ !

La scienza moderna vede nel Radium un mezzo naturale contro l'età che rende preziosi servizi nel senzo del

RINGIOVANIMENTO

I Medici che si occupano della Radium Terapia constatano che la pelle appassita si tende sotto l'influenza dei raggi del radium e ritorna naturalmente fresca e sana. Spariscono le rughe, il rossore del viso e del naso.

LA RADIUM CREMA è meravigliosa per il giorno e la notte! si usa come ogni altra crema.

USATE LA RADIUM CREMA PER 15 GIORNI, giorno e notte e vedrete da voi quali meravigliosi resultati otterrete!

ABBELLISCE! RIANIMA! RINGIOVANISCE!
RIALZA E RASSODA LE FORME
SNELLISCE!

e nello stesso tempo allontana i sintomi di malattie.

DISTRUGGE le cellule stanche e malate e le RIMPIAZZA con cellule nuove e sane.

LA RADIUM CREMA è dosata col contatore di Geiger: ogni tubo contiene 20.000 Mcg. Radium puro. LA RADIUM CREMA non ha niente che vedere con le comuni creme di bellezza e la sua azione è diametralmente opposta, perchè non trucca, non medica, ma fa naturalmente ciò che le comuni creme fanno artificialmente.

LA RADIUM CREMA da resultati sbalorditivi ed entusiasma i clienti che diventano propagandisti convinti e sinceri di questo nuovo agente atomico della natura.

LA RADIUM CREMA deve essere usata da tutti per impedire l'invecchiamento del viso e del corpo, per avere sempre una pelle elastica e giovane ed anche per calmare i dolori di qualunque genere, specialmente reumatici, artritici, ecc. che si può applicare su qualunque parte del viso e del corpo senza la minima controindicazione.

SPECIALMENTE INDICATA NELLE MALATTIE DELLA PELLE RIBELLI AD ALTRI TRATTAMENTI

La crema Atomica RADIUM non è un medicamento nè un cosmetico ed agisce in un modo diametralmente opposto.

Coloro che desiderano la genuina crema atomica «RADIUM» stiano bene attenti a domandare ed esigere la genuina RADIUM-CREMA della Casa SANITAS-OMEGA con la indicazione della quantità di RADIUM puro contenuto in ogni TUBO ORIGINALE: 20.000 Mcg. RADIUM garantito al contatore di Geiger. Rifiutare le imitazioni che non contengono RADIUM prive di ogni efficacia scientifica ESIGERE soltanto i TUBI originali che garantiscono il prodotto genuino in essi contenuto.

SOLAMENTE ORIGINALE IN TUBI

da 20.000 mcg. radium puro garantito al contatore di Geiger

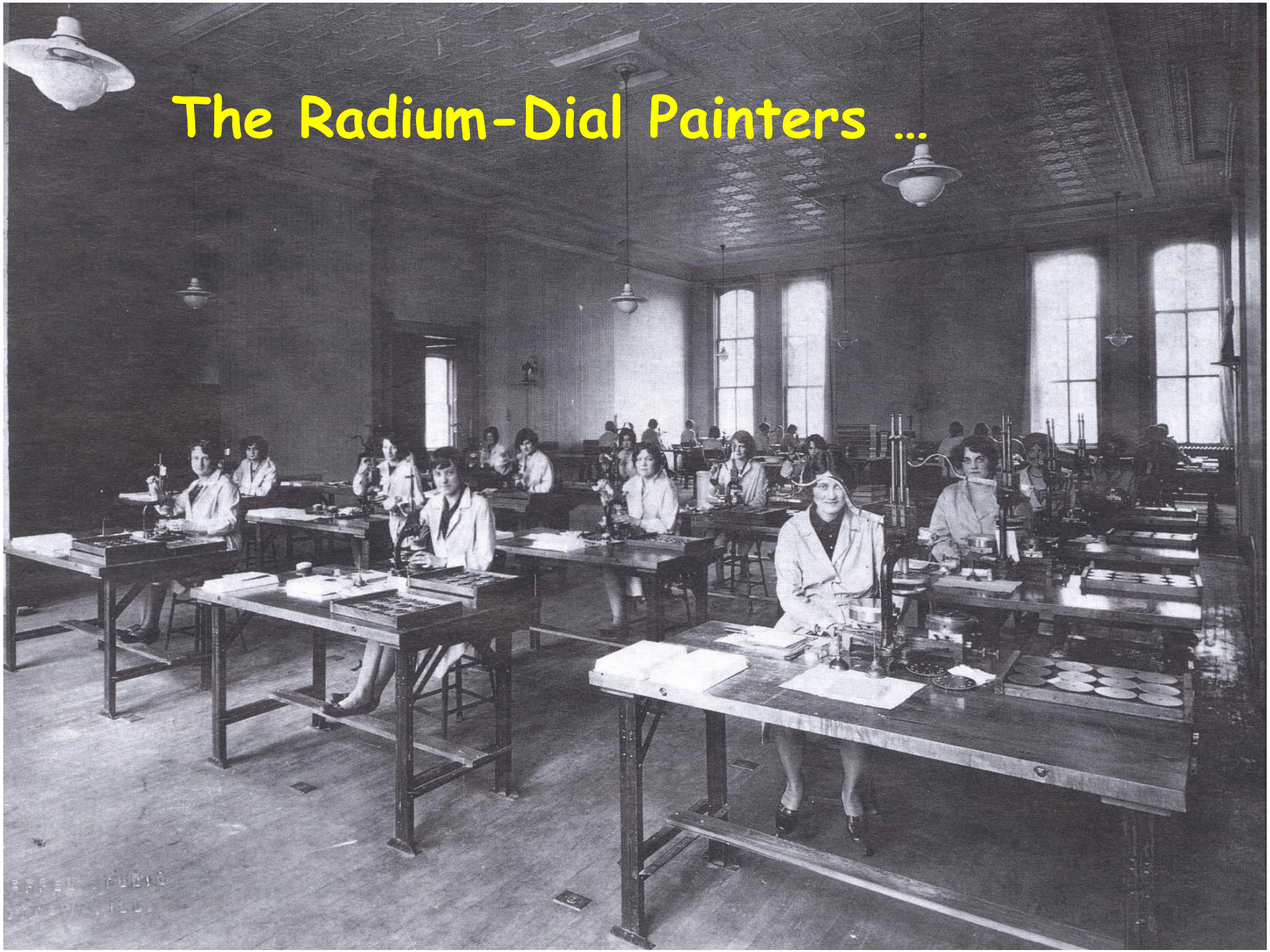
Radium for men

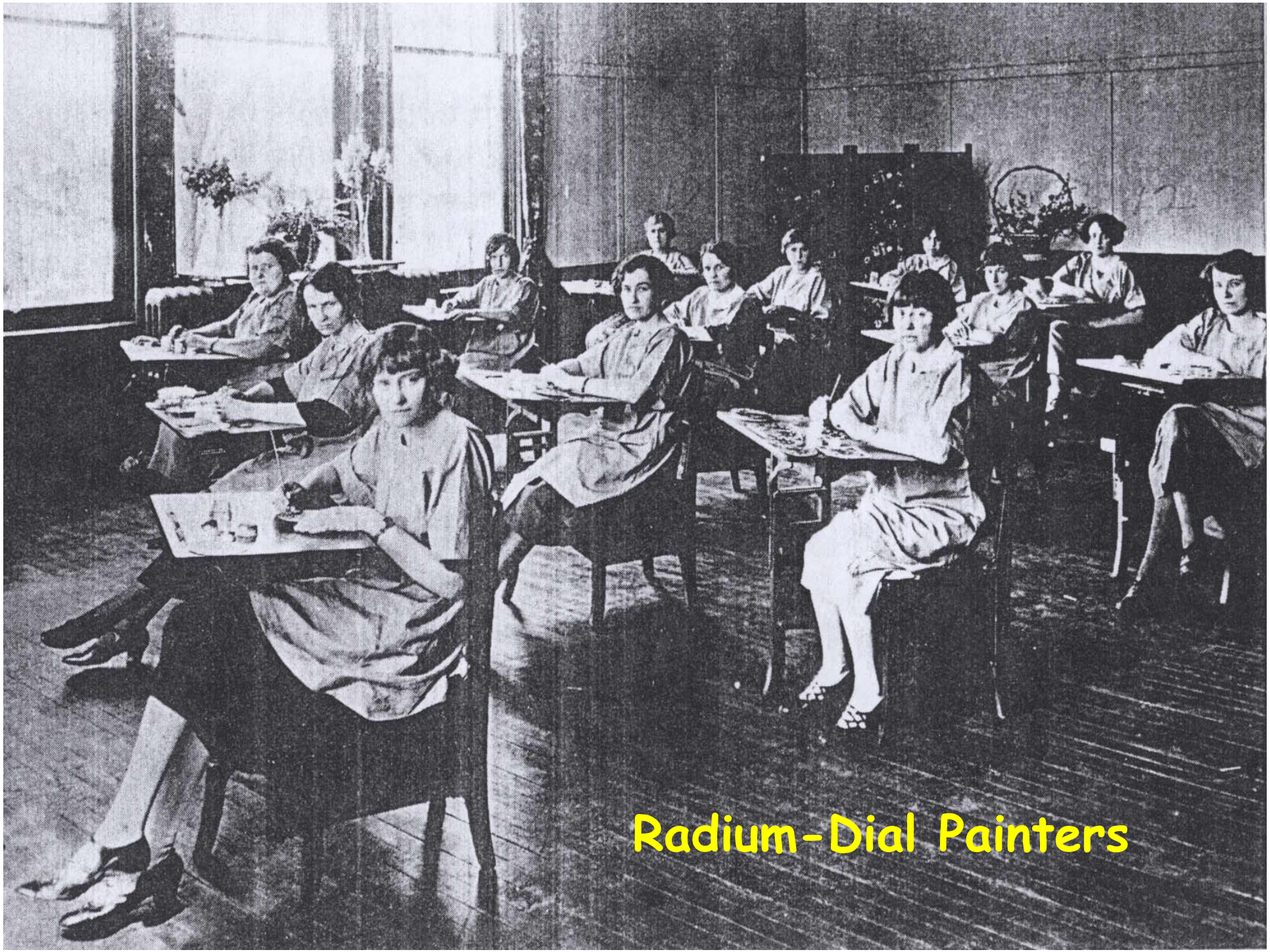
VITA RADIUM SUPPOSITORIES

FOR RESTORING SEX POWER

Actual Size of Vita Radium

VITA RADIUM SUPPOSITORIES, for rectal use by men, are tone restorers of sex and energizers for the entire nervous, glandular and circulatory systems. These Suppositories contain a result-producing amount of highly refined soluble RADIUM, carried in a cocoa butter base. The radium is absorbed thru the walls of the lower colon, enters the blood stream and is carried to all parts of the body —to the weakened organs that need its vitalizing aid. After leaving its durably HEALTHY RESULTS, the radium is gradually eliminated in about three days. Vita Radium Suppositories are guaranteed entirely harmless. Recommended for sexually weak men who, however, should use the NU-MAN Tablets in connection for best results. Also splendid for piles and rectal sores. Try them and see what good results you get!


The Radium-Dial Painters …


Radium-Dial Painters

Radium-Dial Painters

The chronic intake of radium, which is a bone seeker, caused increased rates of bone cancer during the years to follow.

First Treatment of a Cervix Carcinoma with Radium in the Year 1903 by Margaret Cleaves

Medical Record

A Weekly Journal of Medicine and Surgery

Vol. 64, No. 16.
Whole No. 1719.

NEW YORK, OCTOBER 17, 1903.

$5.00 Per Annum.
Single Copies, 10c.

Original Articles.

RADIUM: WITH A PRELIMINARY NOTE ON RADIUM RAYS IN THE TREATMENT OF CANCER.*

By MARGARET A. CLEAVES, M.D.,
NEW YORK.

Not only the scientific world, but the lay as well, listens with bated breath to the marvelous tales of radium; tales which, especially when accompanied by demonstrations of the apparently magical phenomena of this new element, seem more befitting fairy lore than abstruse scientific fact; and one can but wonder whether radium may not prove a veritable Aladdin's lamp to medical science as well as to physics.

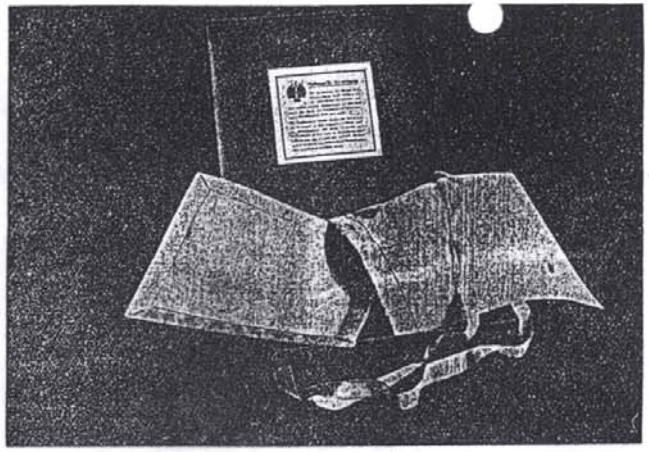
"All nature is vibrating, from the lowest musical note to the highest pitch of the chemical rays," and radium the highest form of etheric vibration is to

In 1898 Prof. Pierre Curie and Mme. Sklodowska Curie, when investigating the radiations from uranium discovered by Becquerel, found that some samples of pitchblende or uraninite, from which uranium is extracted, gave forth radiations much more powerful than any uranium they had found, having four times the activity of metallic uranium.

Painstaking research resulted in the discovery of a substance associated with bismuth and resembling it very much in its chemical characteristics. To this substance Mme. Curie gave the name of polonium, in honor of Poland, the land of her nativity.

Polonium is to be had in the form of a metal and in the form of a subnitrate. The metallic polonium resembles particles of nickel and the subnitrate is a white powder. The only specimen of metallic polonium in this country is in possession of Mr. W. J. Hammer, from whose exhaustive and interesting monograph[1] on radium many facts set forth herein

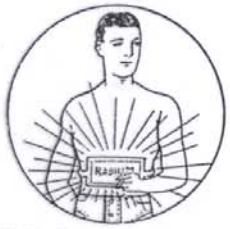
Monument from the year 1936 at St. Georgs Hospital at Hamburg/Germany exhibiting the names 159 doctors, scientists and others which lost their lives because of their work with X-rays and radium.



LA COMPRESSA ATOMICA «RADIUM»

(RADIOANESTETICO)

Dopo il «Radium emanator» che serve a preparare acqua radiata da bere, presentiamo la nuova meravigliosa compressa «RADIUM» gioiello della terapia moderna. La compressa funziona da se e l'elemento radio che genera i suoi effluvi benefici dura per sempre e non può aver mai fine. La compressa «Radium» è formata da un cuscino speciale, di particolare tessuto il cui elemento radio vi è irradiato intimamente con un procedimento ideato dalla «SANITAS» in modo da ottenere una emanazione costante e diretta di tutto il fascio delle irradiazioni: ALFA - BETA - GAMMA. Si è ottenuto così una compressa meravigliosa che ha dato resultati sbalorditivi per la facilità di uso e *per i resultati sorprendenti ed immediati* ottenuti *specialmente nella cura della influenza, grippe, tosse, ecc.* oltre che in una gamma non indifferente di malattie. Si applica instantaneamente ed in modo facilissimo sulla parte che si vuol curare, tanto sul petto che sui polmoni, tanto sul ventre che sulla spina dorsale, tanto sulle braccia come sulle gambe, istantaneamente come un termoforo usuale. Si può tenere tutta la notte senza nessunissimo pericolo e si può portare anche di giorno senza abbandonare le proprie occupazioni. Si consegna munita di federa smontabile e lavabile. In molti casi si raccomandano le compresse «RADIUM» che contengono radium in dose giusta che anche con una continua applicazione non possono mai recare il minimo disturbo. (Citazione da un libro del Prof. Gudzent). Si adoperano con sorprendente successo nelle *infiammazioni, nei dolori da gotta, reumatici, nevralgici, emicranie, malattie dello stomaco, del fegato, dei reni, della bile, nelle conseguenze della vecchiaia, nella insonnia e nella cura meravigliosa e sorprendente di tante altre malattie.* Visto che il «Radium» ha una durata di migliaia di anni le compresse durano sempre.



Malattie dello stomaco fegato - intestino
Benessere immediato dopo l'applicazione.

Grippe - tosse - influenza
La tosse passa e si calma subito. Si avverte un miglioramento immediato, applicando sul petto.

Dolori ai reni sciatica - lombaggine
Il dolore passa subito dopo l'applicazione sulla parte dolorante, che è facile ed immediata.

Dolori della gotta reumatici - nevralgici
Niente eguaglia la portentosa rapidità del Radium nella cura di queste malattie. Miglioramento immediato, nelle infiammazioni, paralisi ecc.

Nevralgia - Emicrania
Il dolore passa subito!

Malattie della gola naso - orecchi
Il dolore passa subito!

Malattie degli orecchi
Il dolore passa subito!

Malattie dei denti e della bocca
Il dolore passa subito!

La COMPRESSA «RADIUM» che contiene radio elemento garantito e bollato, da dei resultati prodigiosi e sbalorditivi. Immediatamente dopo averla applicata, passa la tosse, si calma il dolore, si avverte subito un benessere generale, apportatore di ristoro, di conforto, di nuova energia e di guarigione. Per apprezzare la COMPRESSA come essa merita, le parole non bastano! Bisogna provarla per constatare da se stessi la sua prodigiosa, meravigliosa, rapidissima azione risanatrice nelle malattie più disparate.

Il valore dipende dalla quantità del «RADIUM» adoperato. Per verificare se una compressa contiene o no del «RADIUM» si fa un radiogramma con una fotografia semplicemente alla compressa. La fotografia *dice* se la compressa contiene o non contiene radium. (Vedi pag. 7) LA COMPRESSA «RADIUM» CURA PRODIGIOSAMENTE.

Prof. Gudrenz *I.a Clinica interna di medicina a la Charité afferma:*

«Noi usiamo nella nostra clinica le compresse «RADIUM» che in effetto si sono rivelate molto preziose grazie al loro effetto lenitivo in caso di nevralgie, sciatiche, di affezioni reumatiche, fratture e ferite.

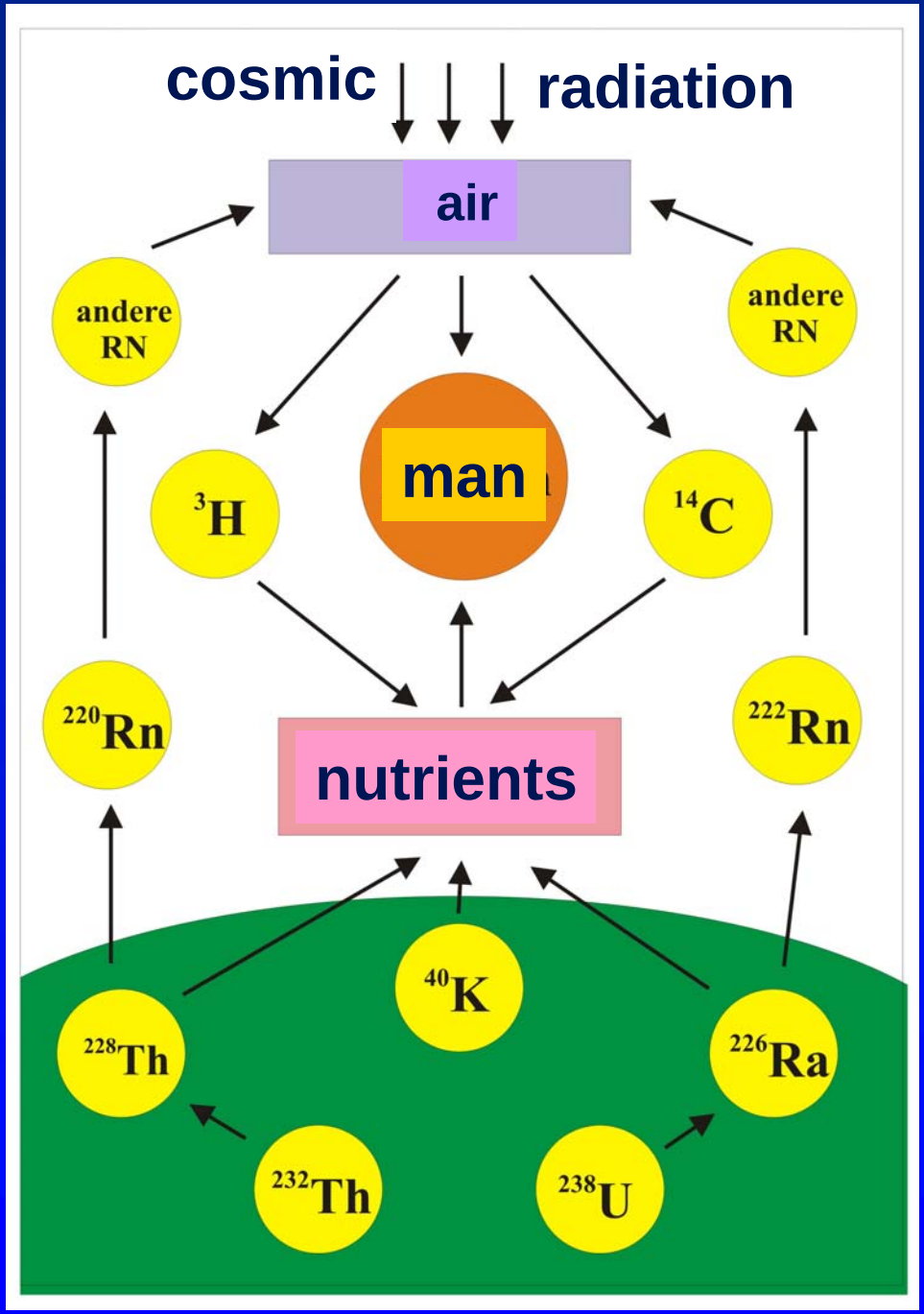
(Arztliche sammelblater 10-3-1954)

LA COMPRESSA RADIUM può essere facilmente unita a termoforo elettrico «OMEGA» come mostra la illustazione per applicarla a doppio effetto: emanatore dei raggi del RADIUM e calore nei casi di influenza, grippe, tosse, bronchite, sciatica, nevralgia ecc.

Radiation-Induced Cancer as a Consequence of Application of a Radium Cushion

R. Michel, ZSR, Leibniz Universität Hannover

The Radiation Exposure of Man



Man in the Cosmic and Terrestrial Radiation Fields

Natural Radiation Exposure:

- **cosmic radiation**
- **terrestrial radiation**
- **incorporated radionuclides**

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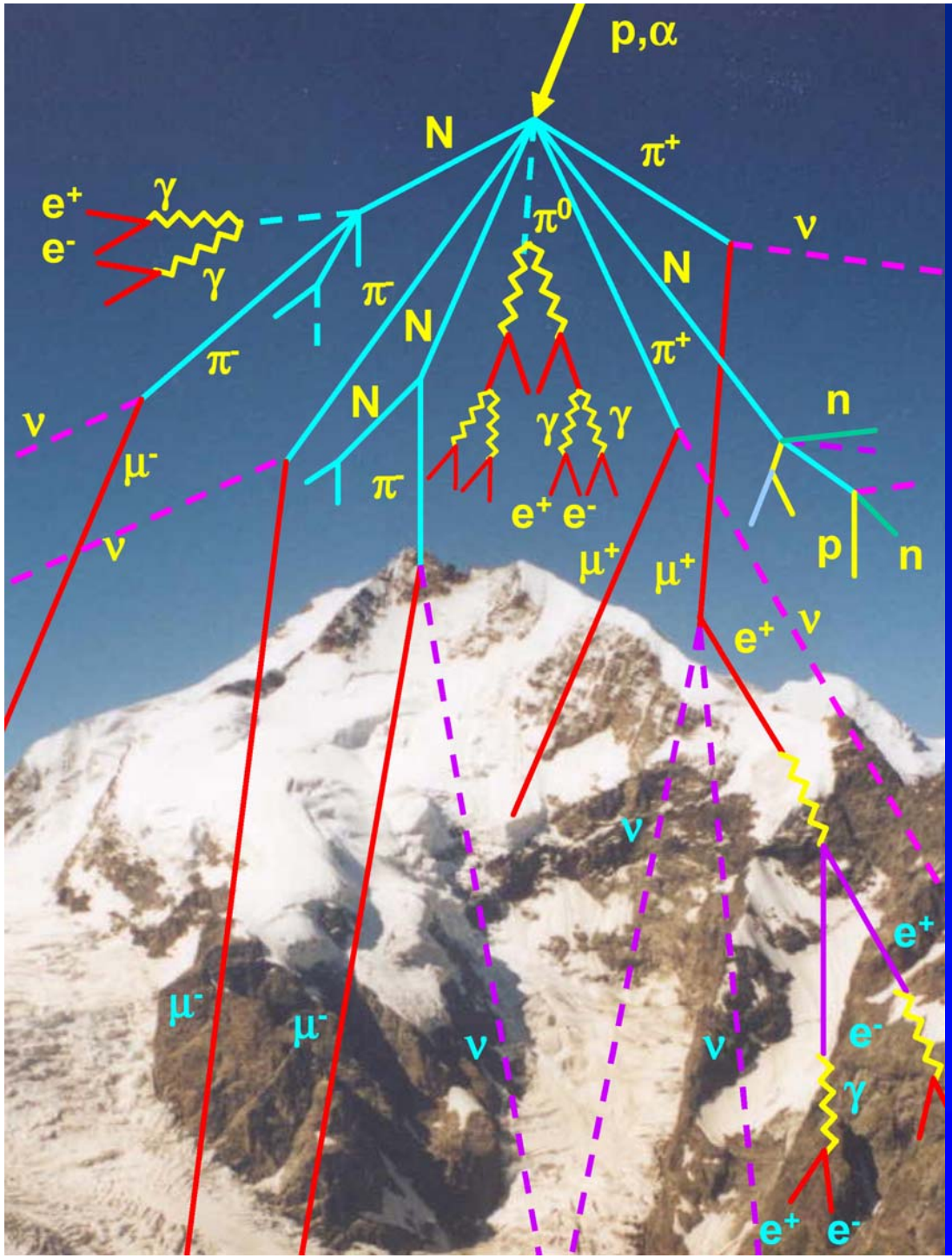
Natural Radiation Exposure

The natural radiation exposure consists of:

exposure to cosmic radiation
exposure to terrestrial radiation
exposure to radiation from incorporated radioactive nuclides



Cascade shower over Piz Bernina

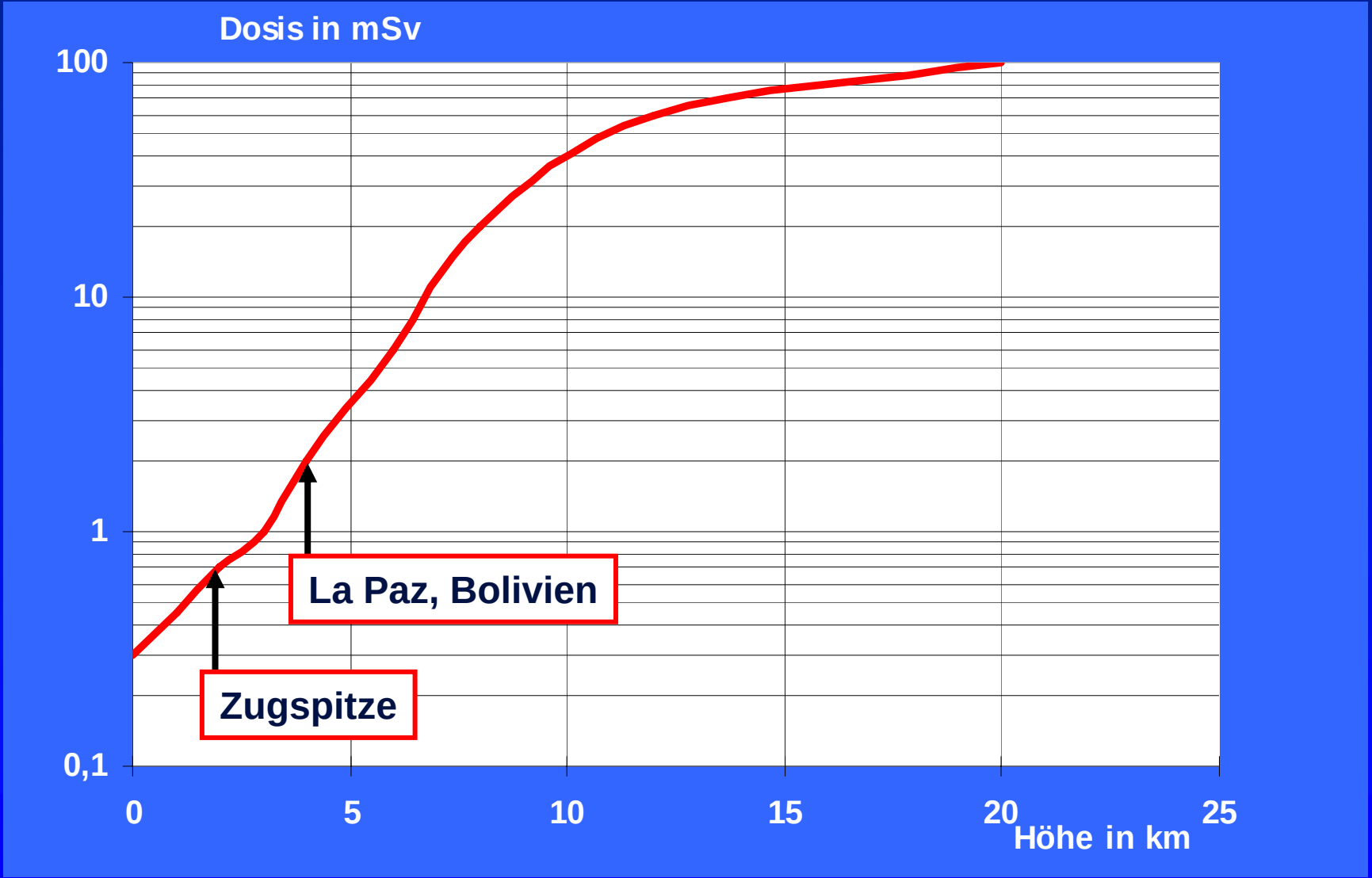
N	atomic nuclei
μ	muons
ν	neutrinos
π	pions
γ	gammas
e	electrons
p	protons
n	neutrons

Atomic nuclei and pions cannot reach the deeper layers of the atmosphere.

R. Michel, ZSR, Leibniz Universität Hannover

Ambient Dose rate of the Cosmic Radiation

mean value per year in Europe



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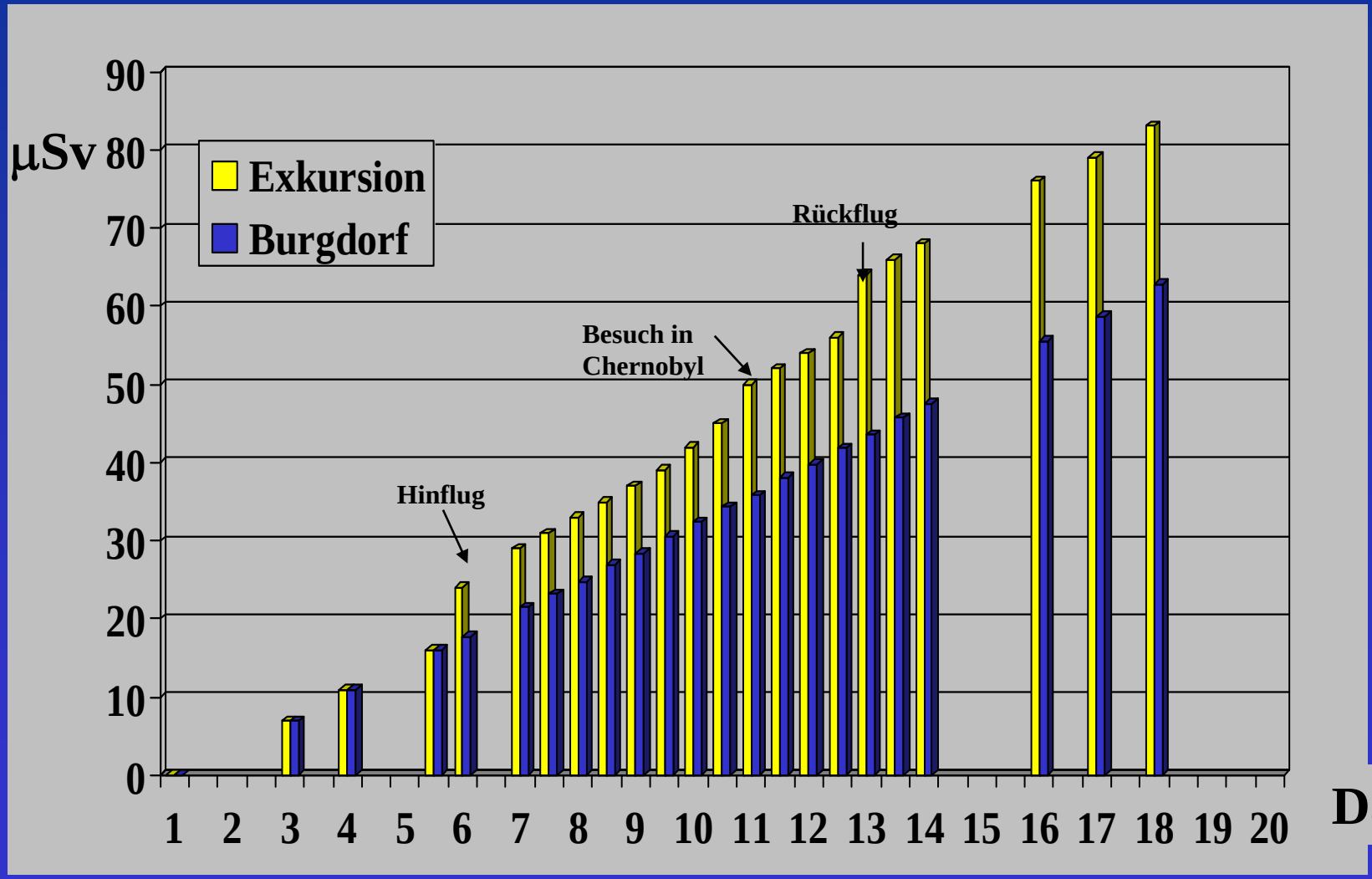
Exkursion vom nach Zhitomir & Chernobyl
6.4. - 13.4.1997; ALNOR RAD-21 LE-µSv



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Terrestrial Radiation

Most natural radionuclides belong to the natural decay series:

Uran/Radium-series U-238 (T = $4{,}5 \cdot 10^9$ Jahre)

Uran/Actinium-series U-235 (T = $7 \cdot 10^8$ Jahre)

Thorium-series Th-232 (T = $1{,}4 \cdot 10^{10}$ Jahre)

Age of the solar system: $4{,}55 \cdot 10^9$ Jahre

T half-life

Some Primordial Radionuclides which are not Members of a Decay Series

Nuclide	half-life in years
K-40	$1{,}3 \cdot 10^{9}$
Rb-87	$4{,}8 \cdot 10^{10}$
Sm-148	$7{,}0 \cdot 10^{15}$
Pt-190	$6{,}1 \cdot 10^{11}$
Pb-204	$1{,}4 \cdot 10^{17}$

Terrestrial Radiation Exposure in Germany

	ambient dose		annual effective dose in mSv			
persons stay	dose rate in nGy/h	dose per year in μGy	adult	10 years	5 years	1 year
at open air	54	473	341	378	402	426
in houses	70	613	442	491	521	552
80% in houses, 20% open air		**585**	**420**	**470**	**500**	**530**

R. Michel, ZSR, Leibniz Universität Hannover

Internal Radiation Exposure due to Ingestion of Natural Radionuclides

Natürliche Radionuklide in Nahrungsmitteln.

Natürliche Radionuklide im menschlichen Körper (sogenannter „Standardmensch").

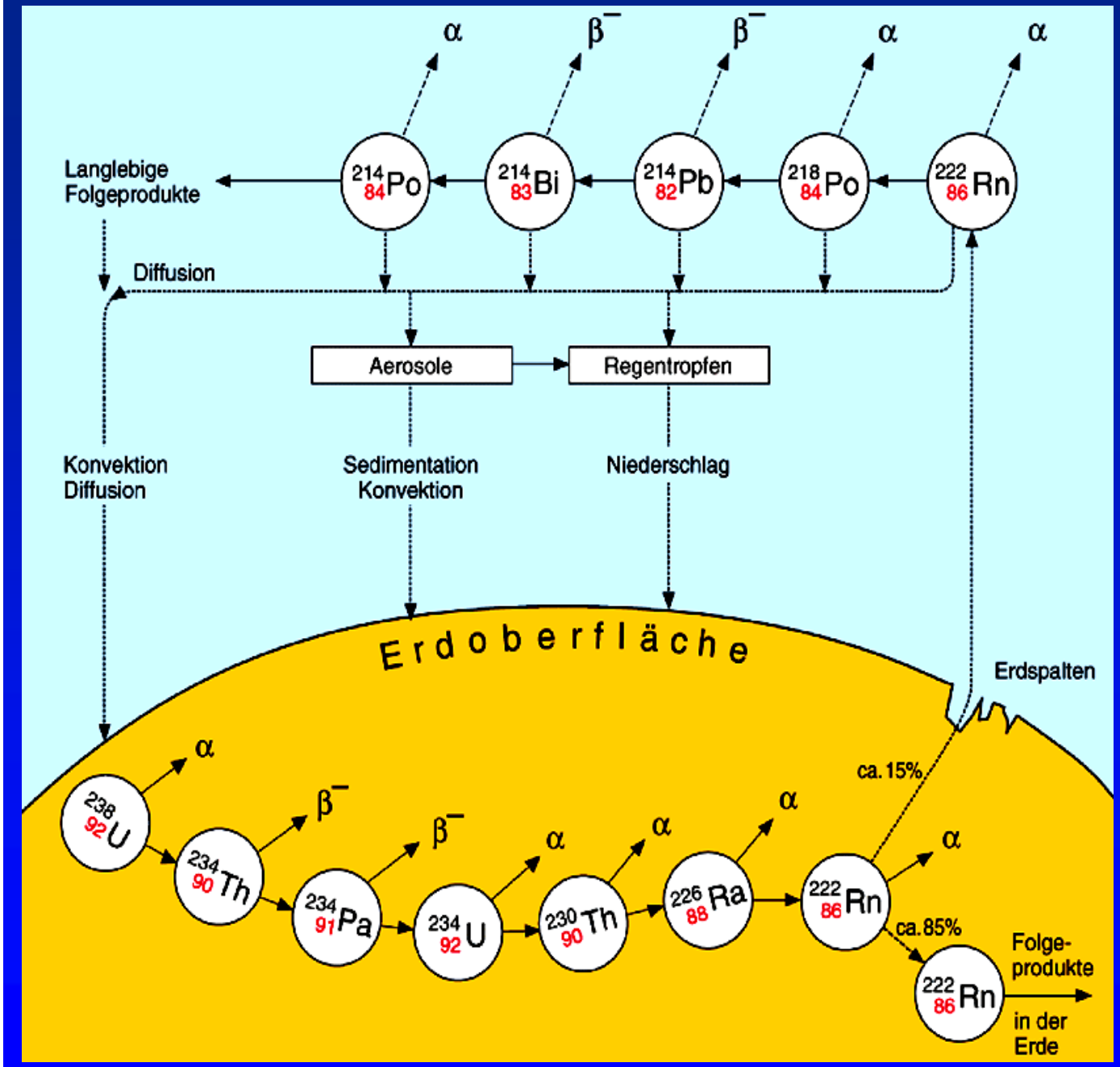
R. Michel, ZSR, Leibniz Universität Hannover

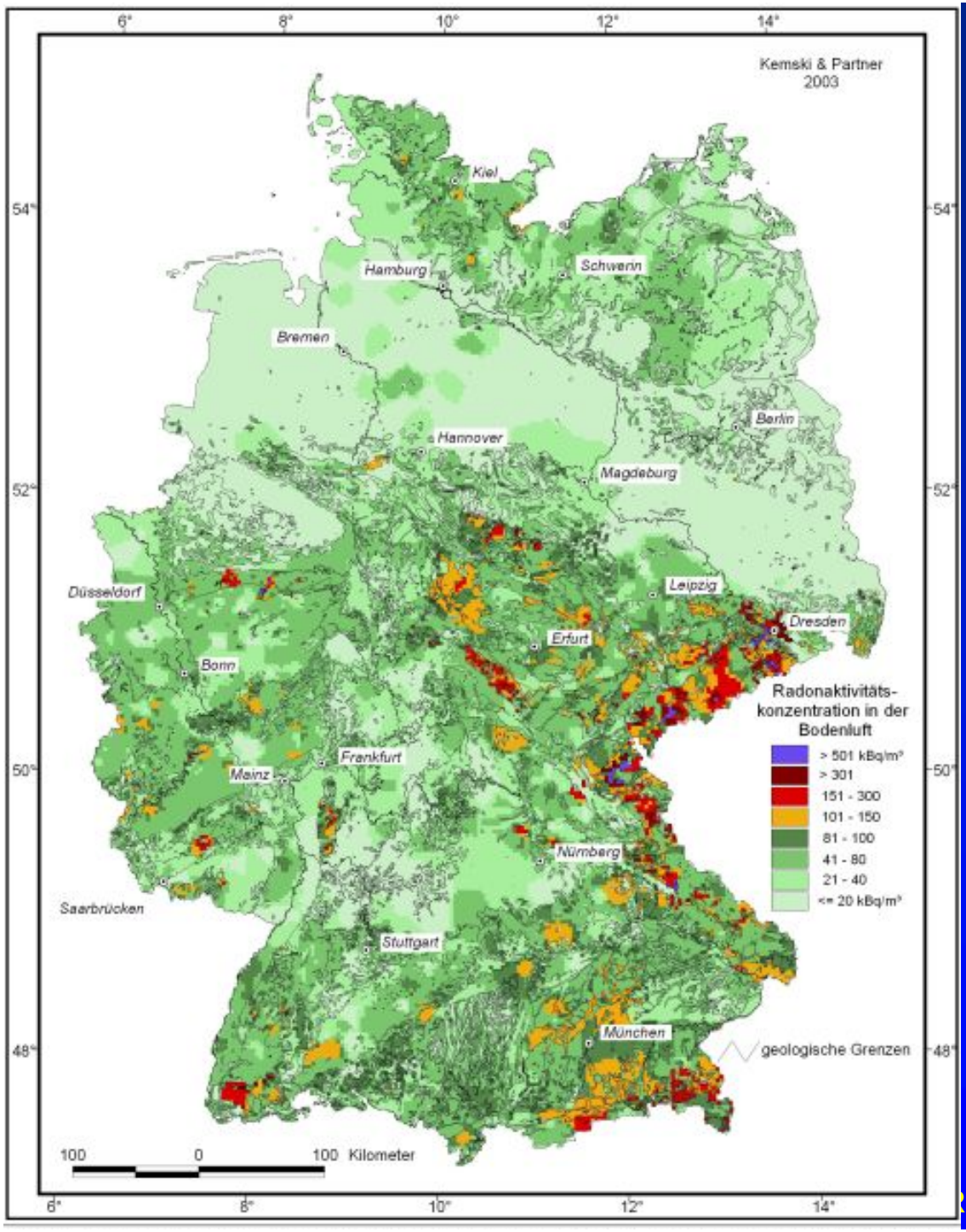
Mean Content of Natural Radionuclides in Man

radionuclide	activity in Bq
K-40	4400
C-14	4000
Rb-87	300
H-3	20
Pb-210	14
Po-210	12
U-238	1,1
Ra-226	1,7
others	1

Radon

Origin of Rn-222 and its progeny in air





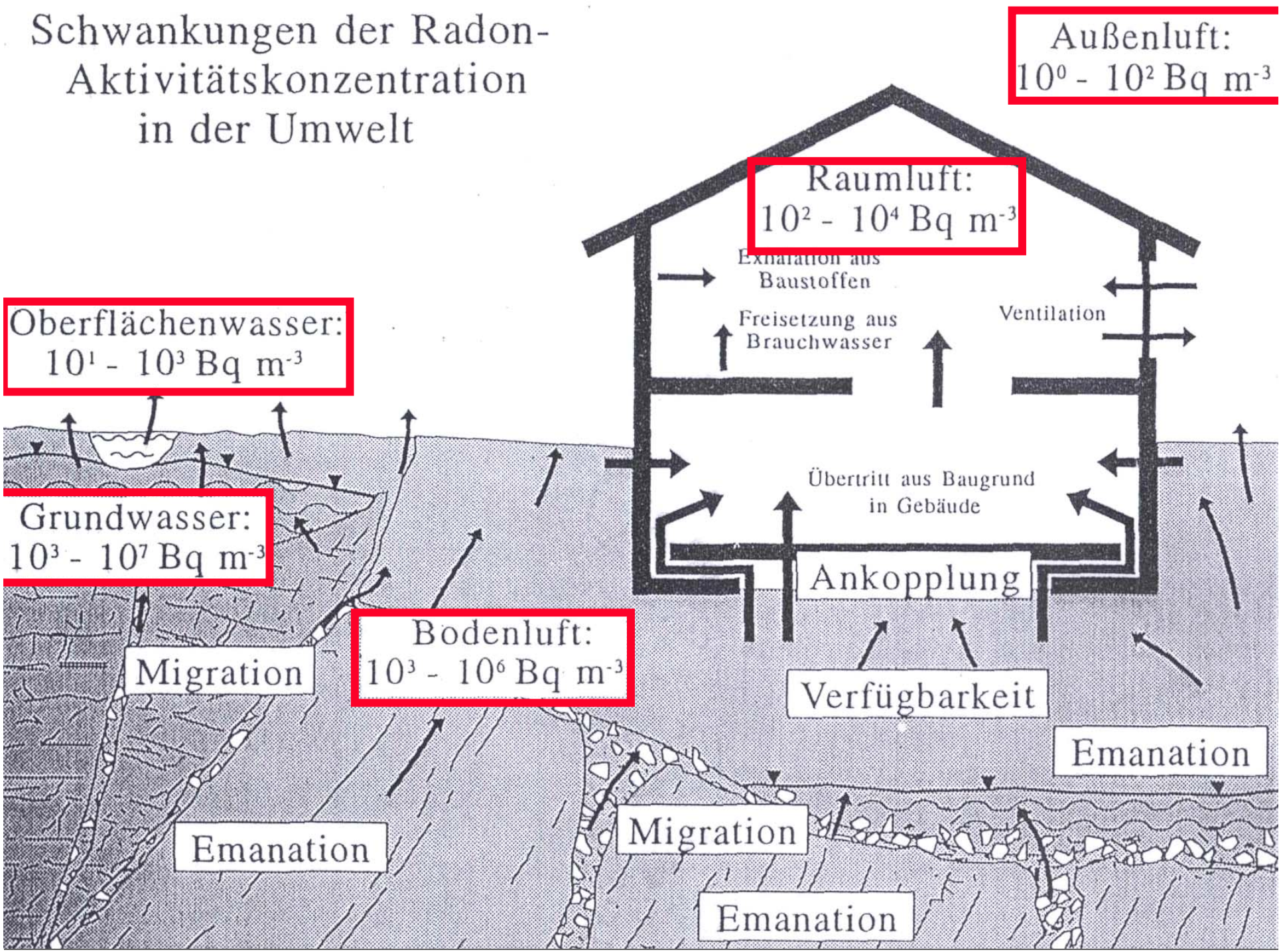
Radon in soil air

BfS (2005)

- > 501 kBq/m³
- > 301
- 151 – 300
- 101 – 150
- 81 – 100
- 41 – 80
- 21 – 40
- ≤ 20 kBq/m³

R. Michel, ZSR, Leibniz Universität Hannover

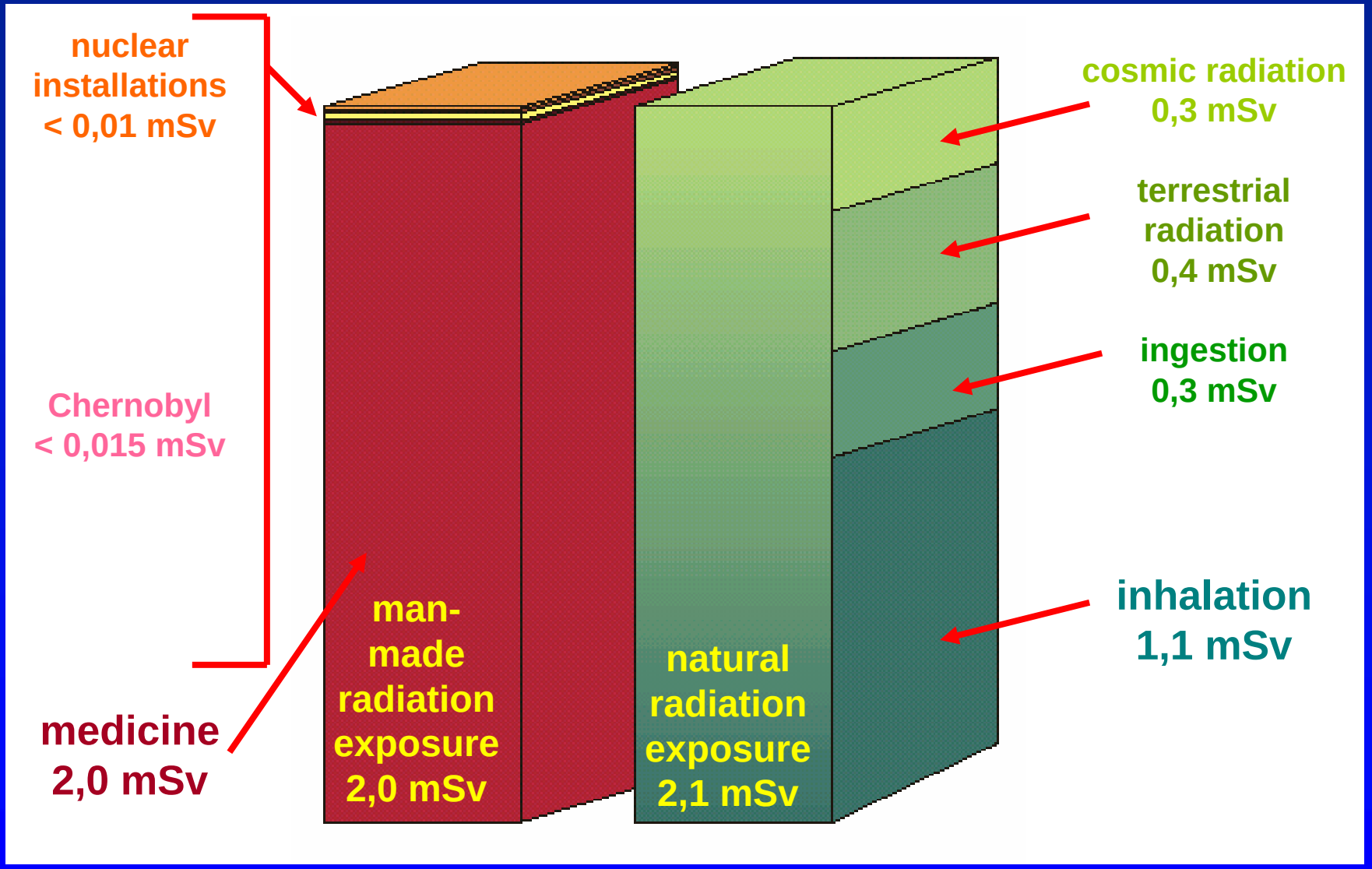
Schwankungen der Radon-Aktivitätskonzentration in der Umwelt



Mean Radiation Exposure per Year due to the Entire Natural Radiation

	organ dose in mSv		
radiation component	gonads	bones	lungs
cosmic radiation	0.3	0.4	0.4
terrestrial radiation	0.6	0.6	0.6
internal radiation	0.2	1	10.2
Sum	1.1	2	11.2

Mean Annual Effective Dose due to Ionizing Radiation in Germany in the Year 2000



BMU, Bundestagsdrucksache 14/6905, 10.09.2001

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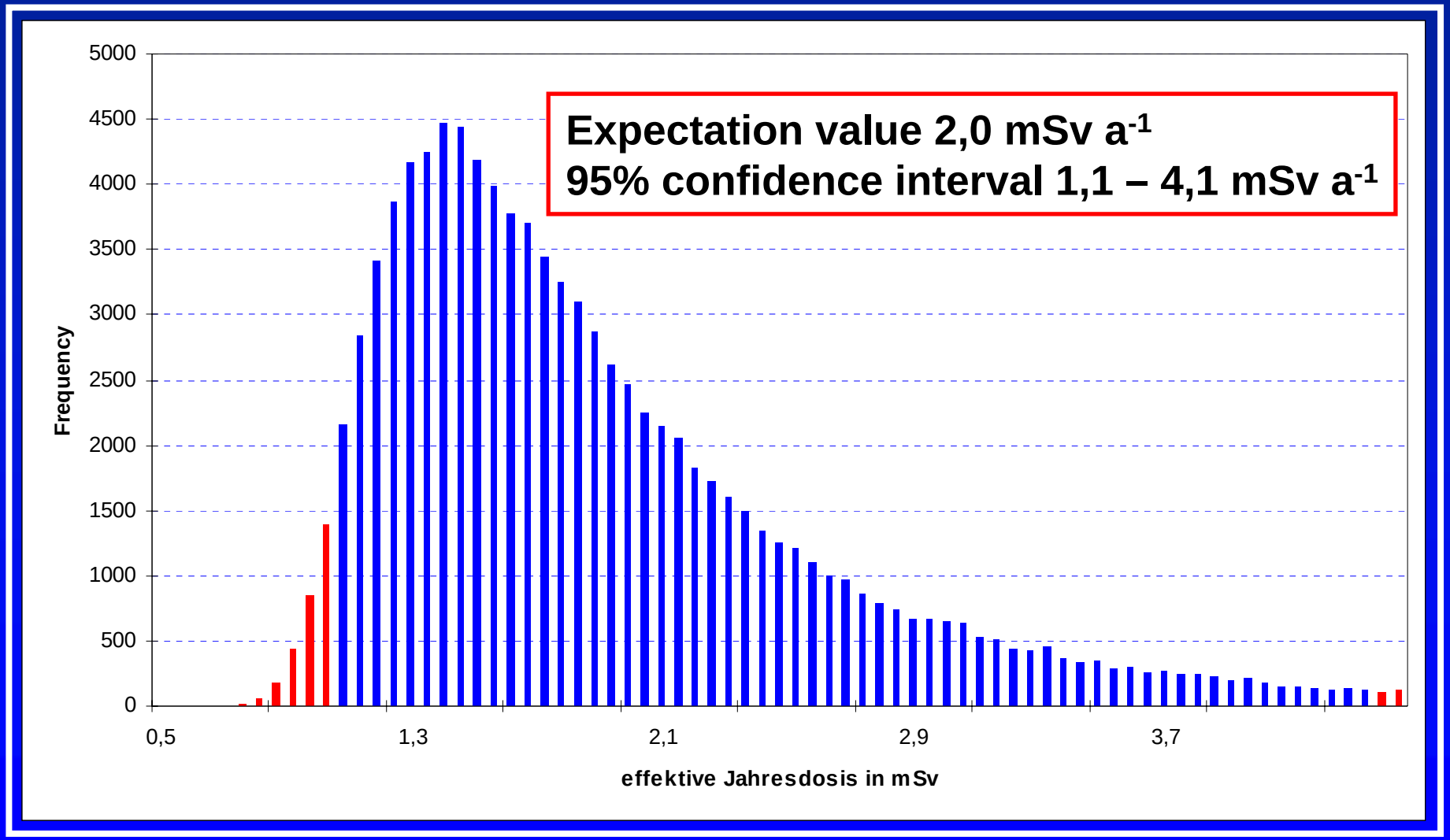
Probability distribution of the annual effective dose in Lower Saxony (Germany)



Vahlbruch (2004)

Statistische Kenngrößen der gesamten altersgemittelten natürlichen effektiven Jahresdosis in mSv in Deutschland und ausgewählten Bundesländern

	mean	typical range	
World [1]	2,4	1,0	10
Germany [2]	2,1	-	-
	expectation	2,5% percentile	97,5% percentile
Germany	2,2	1,2	4,6
Lower Saxony	2,2	1,2	4,7
Saxony	2,6	1,2	6,3
Rhineland-Palatine	2,8	1,2	6,2
Aue/ Saxony	2,6	1,2	6,3

[1] UNSCEAR (2000)
[2] BfS (2005)

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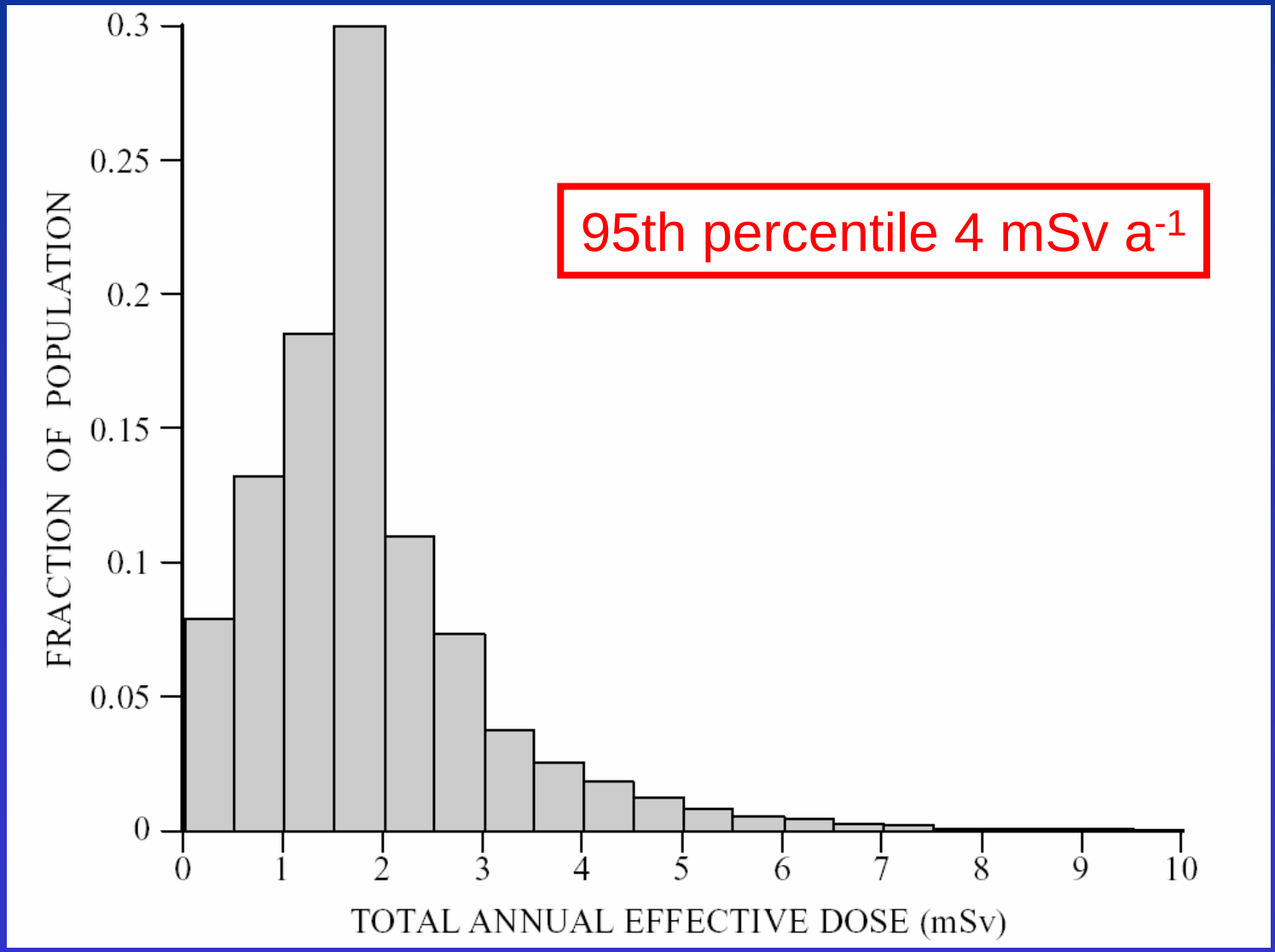
Distribution of annual doses from natural sources in 15 countries.



UNSCEAR (2000)

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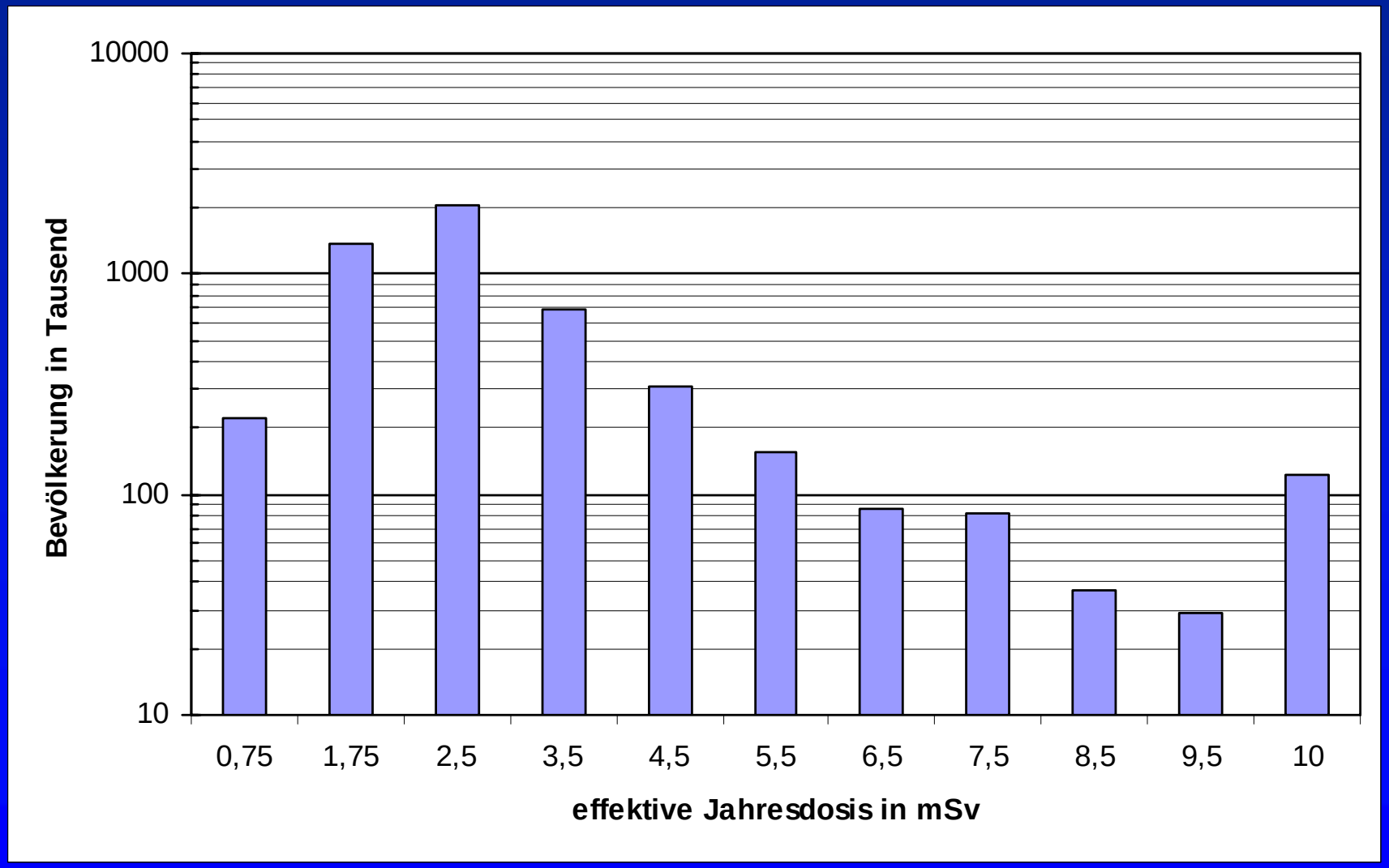
Distribution of the natural radiation exposure in Finland



UNSCEAR (2000)

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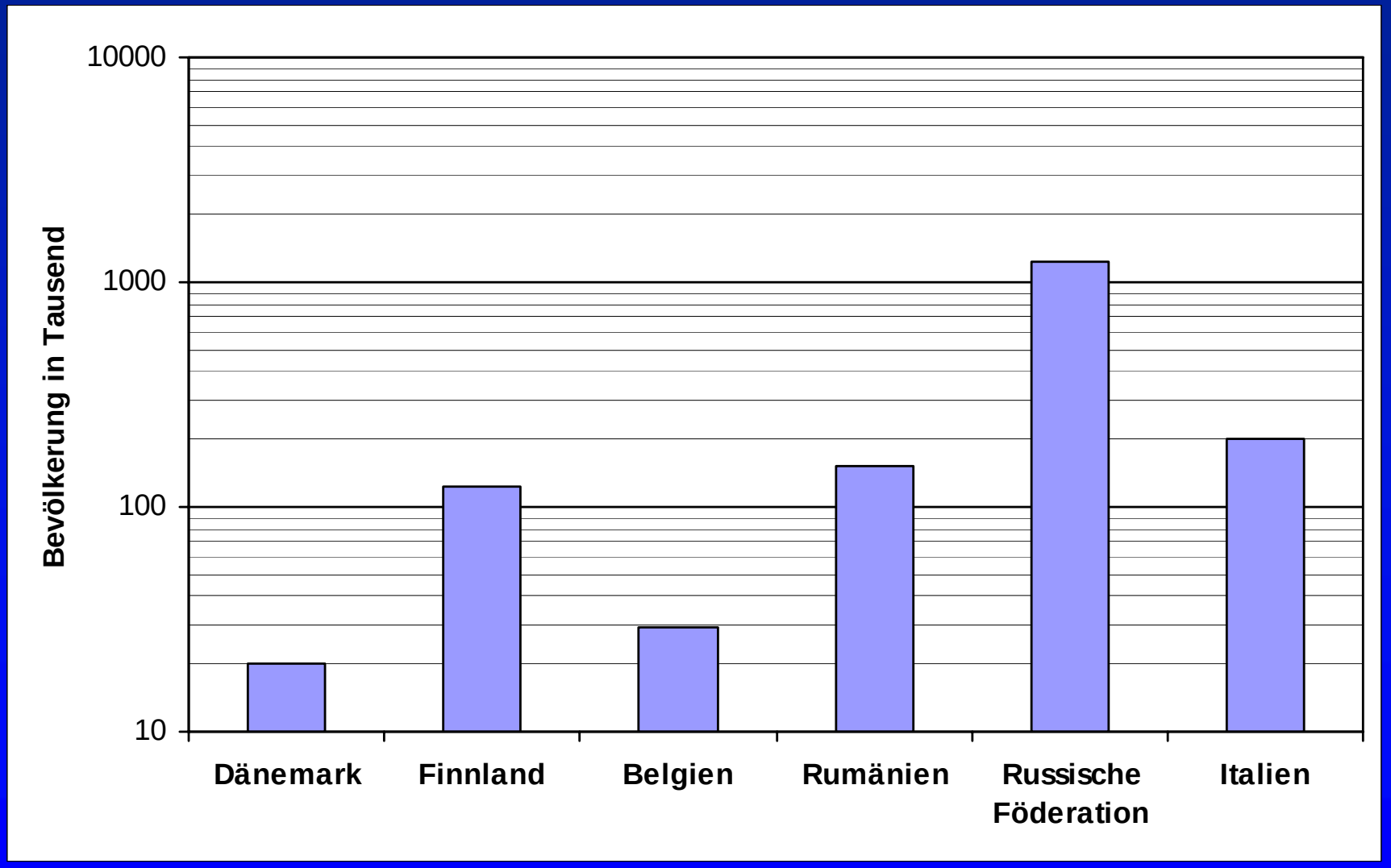
Populations with more than 10 mSv a^{-1} natural radiation exposure



UNSCEAR (2000)

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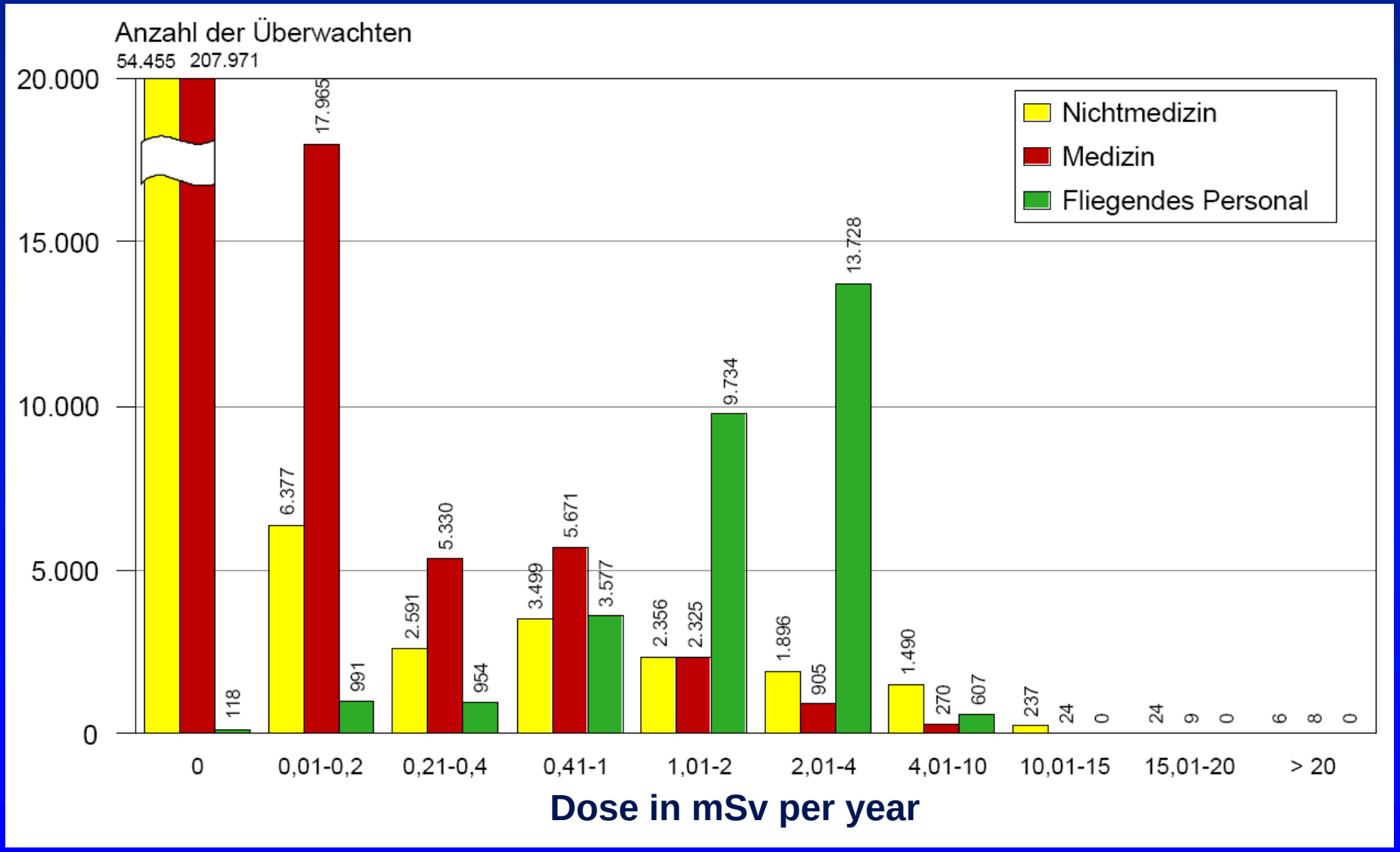
Frequency Distribution of Person Doses of Radiation Workers in the Year 2004



BMU, Bundestagsdrucksache 16/200, 09.12.2005

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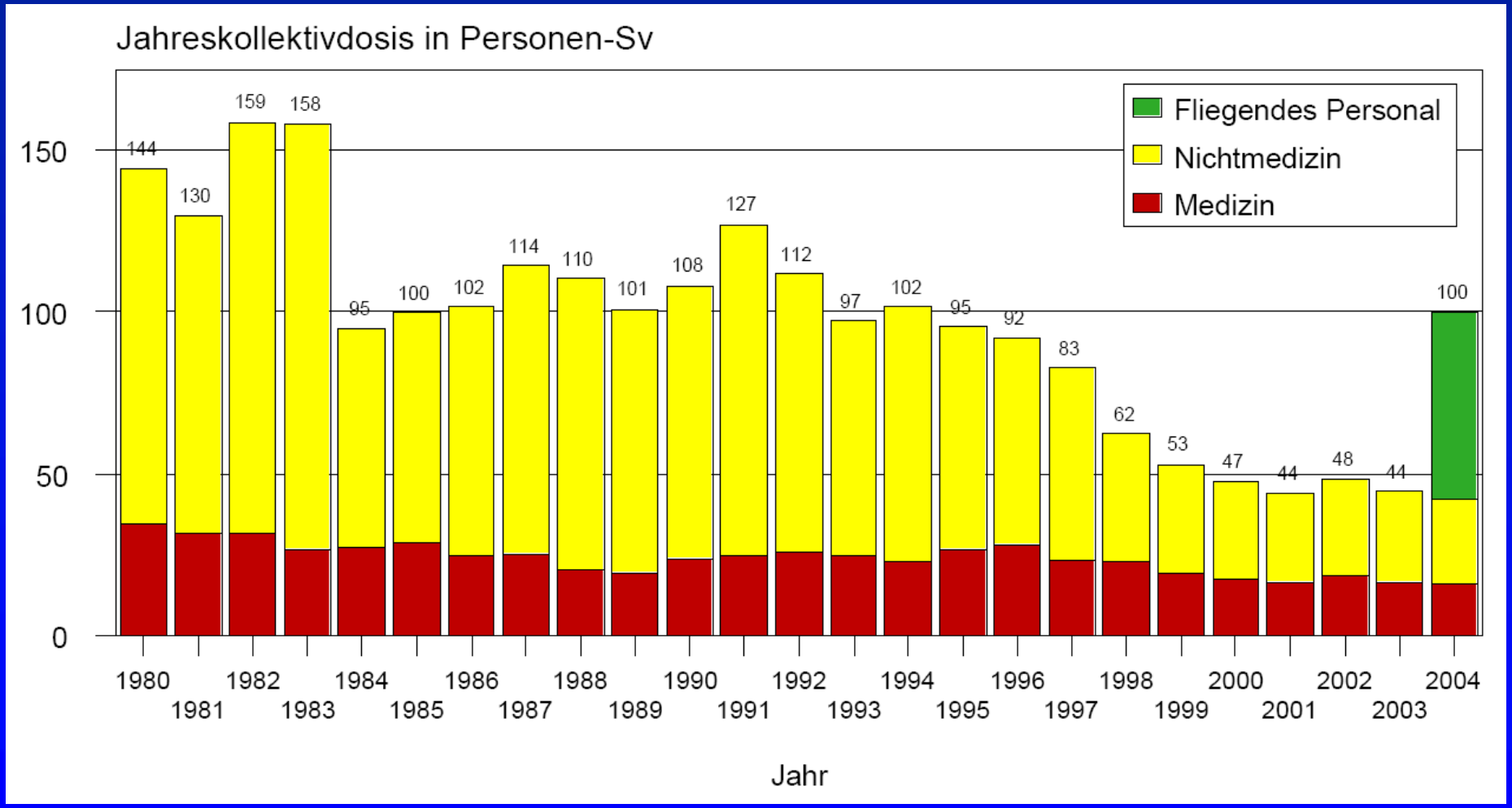
Development of annual collective roses of radiation workers (since 1990 including the former GDR)



BMU, Bundestagsdrucksache 14/6905, 10.09.2001

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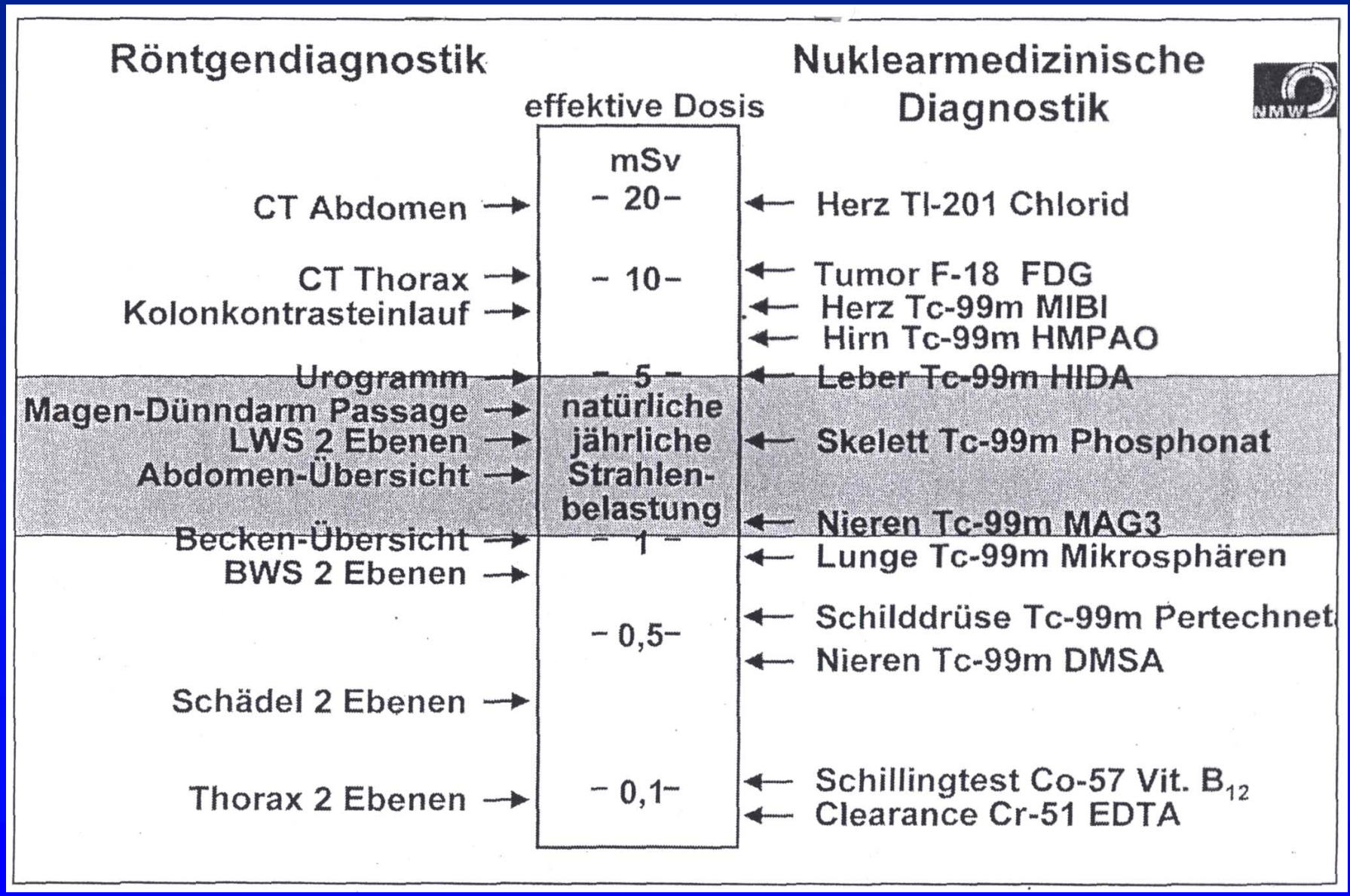
Radiation exposure due to medical diagnostics



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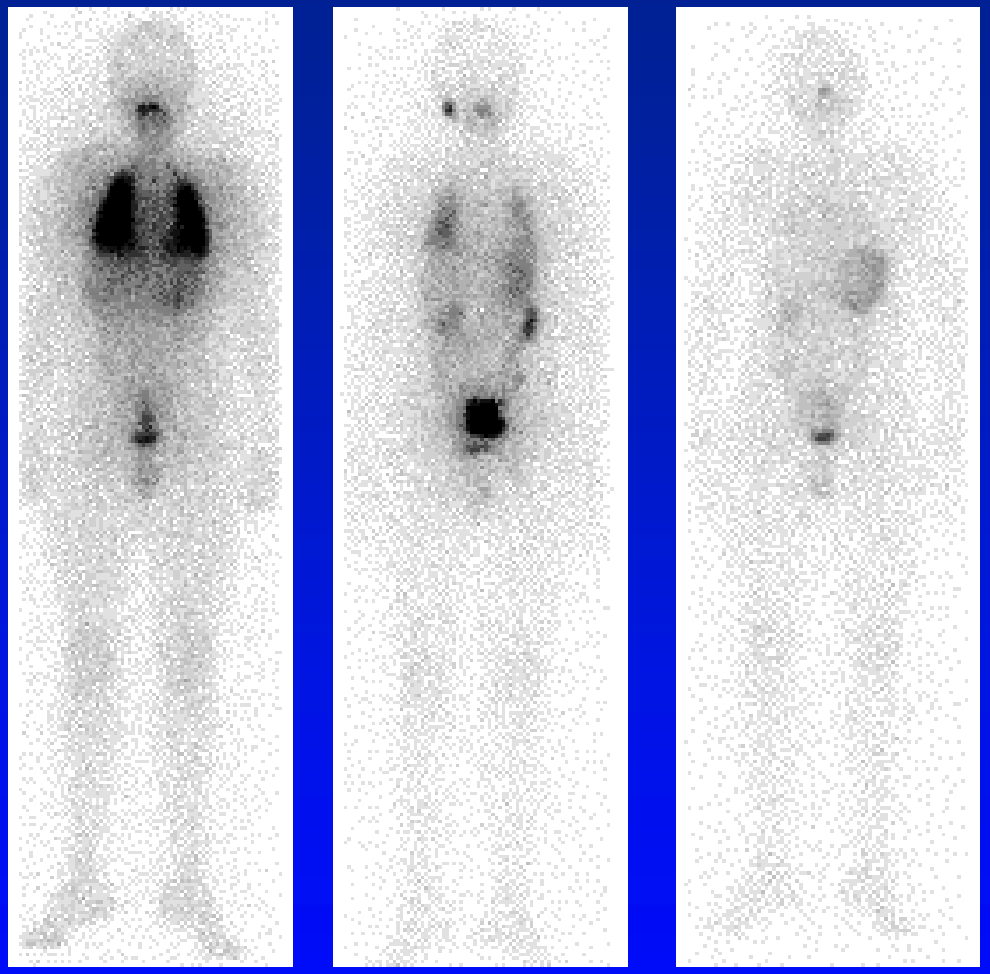
I-131 Therapy of Thyroid Cancer

4 therapies,
each with 6 GBq I-131

Scintigraphies after the 1., 2. and 4. therapy for a child from Belorussia for which a cancer was diagnosed at age 13.

A consequence of the Chernobyl accident.



02/95 **12/95** **07/96**

Radiation Exposure in Therapy

Example: Radio-Iodine Therapy of Benign Diseases

Morbus Basedow
target dose of the thyroid gland: 200 Gy – 300 Gy

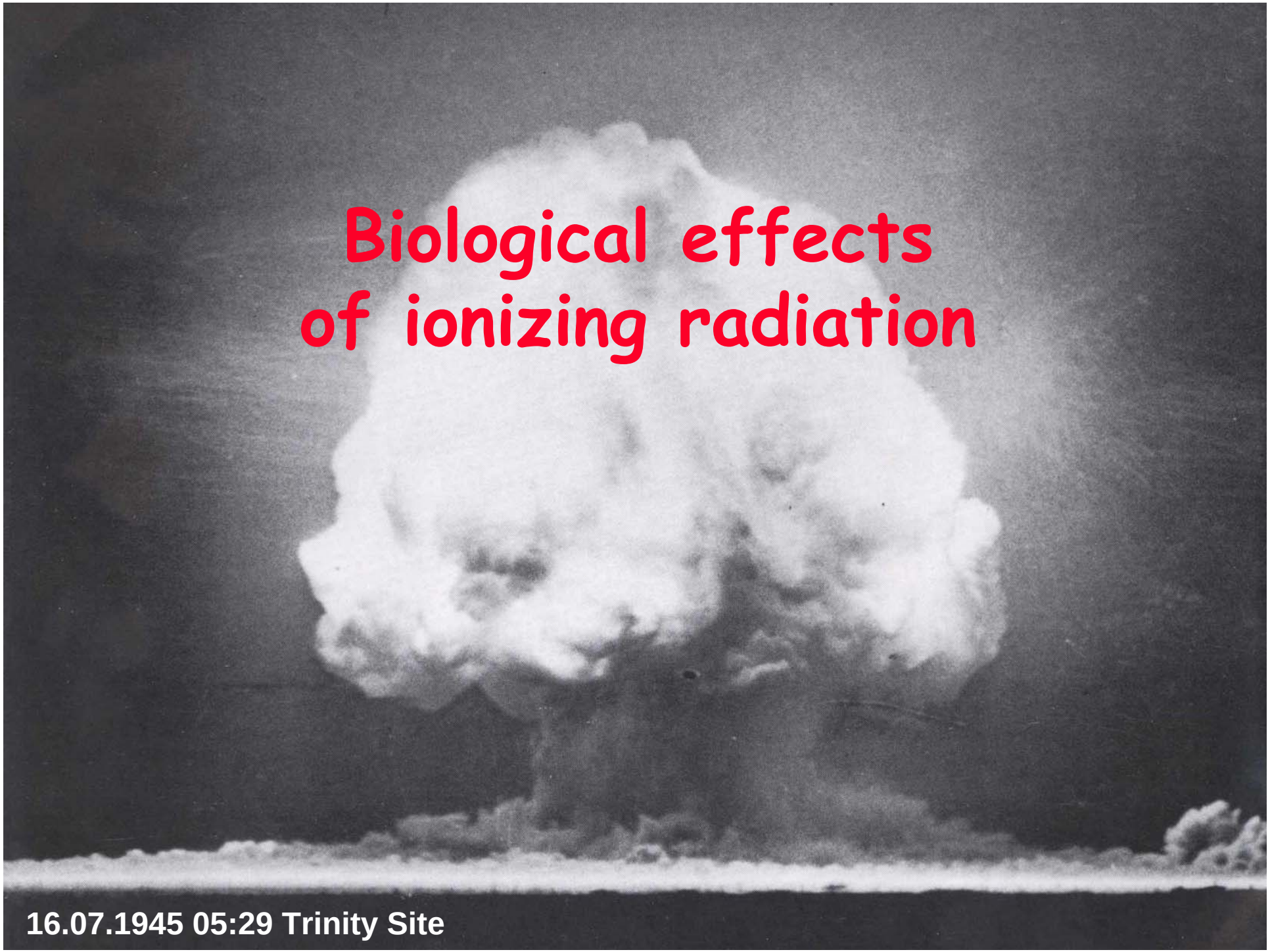
Example: Thyroid Cancer

therapies with 6 GBq I-131 each

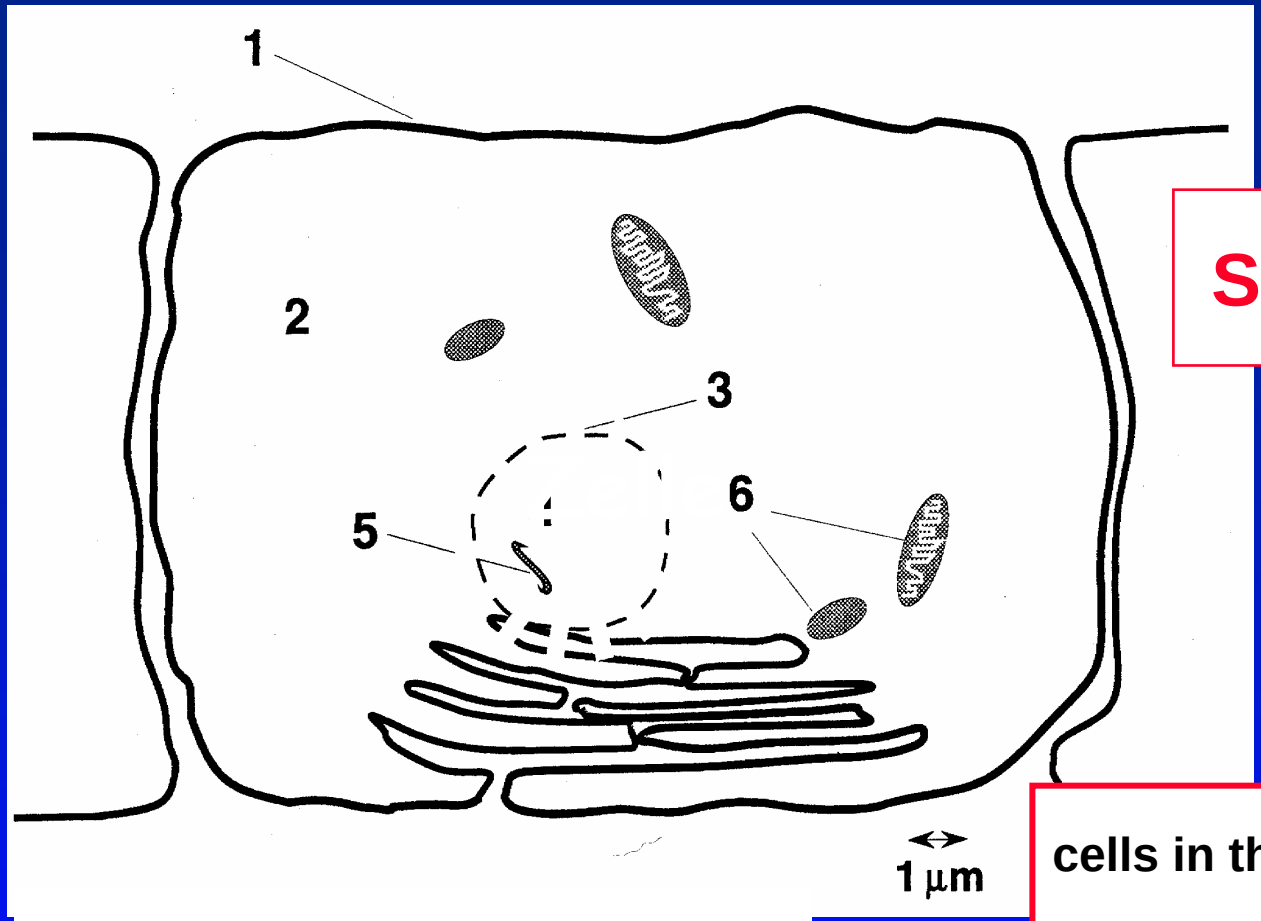
$DF_{thyroid,\ adult}$**(I-131) = 4,3E-7 Sv/Bq**

$DF_{thyroid,\ 15\ a}$**(I-131) = 6,8E-7 Sv/Bq**

⇒ **adult:** $D_{thyroid}$ **= 2580 Gy**
⇒ **15 years old:** $D_{thyroid}$ **= 4080 Gy**


Biological effects
of ionizing radiation
16.07.1945 05:29 Trinity Site

Scheme of a Cell



1 Cell membrane
2 Plasma
3 Membrane of the nucleus
4 Nucleus
5 Chromosome
6 Cell organelle

cells in the human body 10^{14}

genes per cell $\approx 3 \cdot 10^4$

chromosomes (man) 46

production of cells per day

skin	$0{,}7 \cdot 10^9$
stomach-intestine	$56 \cdot 10^9$
erythrocytes	$200 \cdot 10^9$

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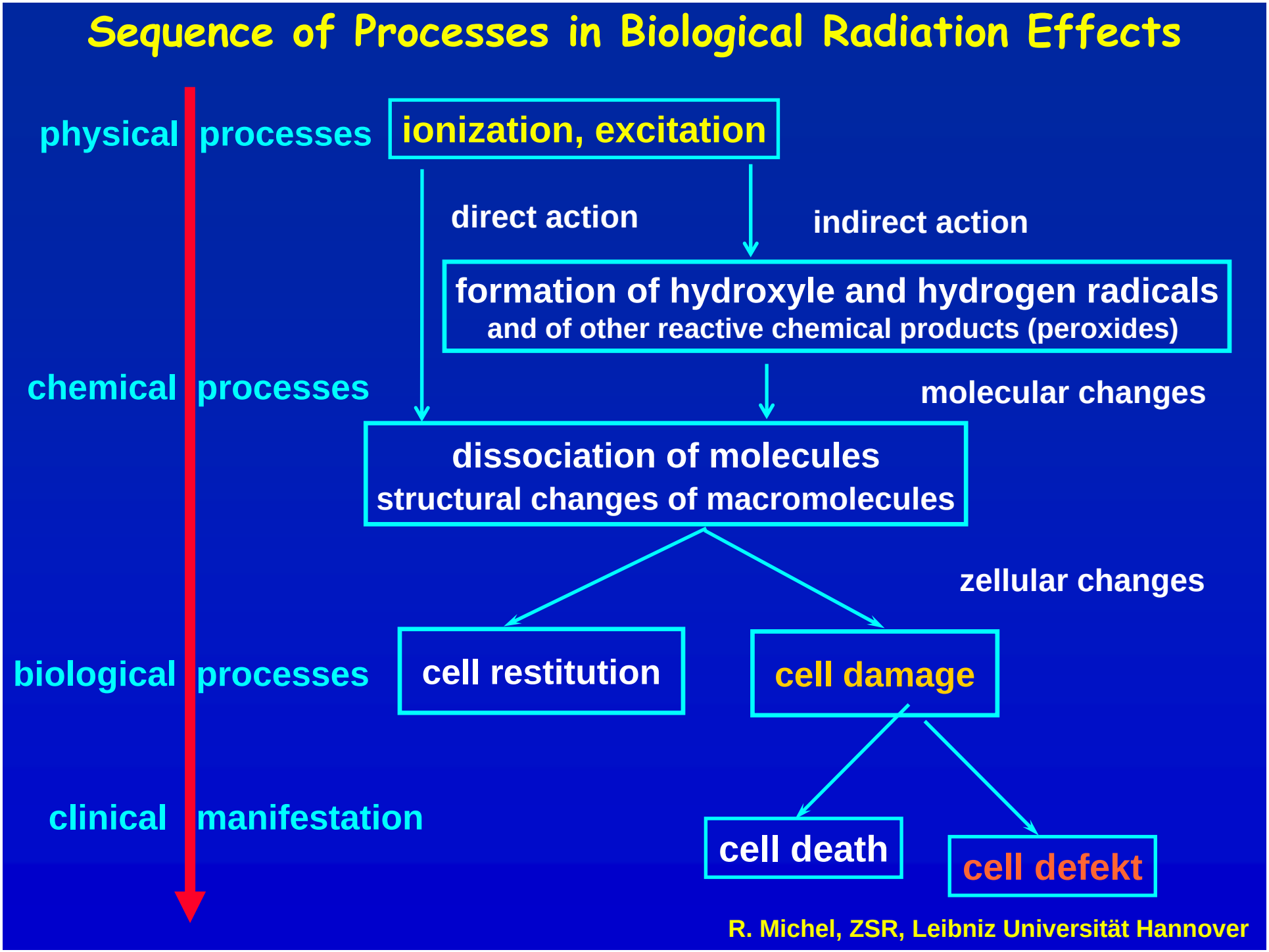
Sequence of Processes in Biological Radiation Effects



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Time Scales of Biological Processes after Irradiation

Stadium	Process	Duration
physical stadium	ionisation and excitation Life-time of ion pairs	$< 10^{-15}$ s
chemical stadium	life-time of free radicals breaking of chemical bonds	10^{-15} - 10^{-6} s $< 10^{-13}$ s
biochemical and biological stadium	enzymatic repair acute radiation syndrome latency period for carcinogenesis	1 min - 10 h 1 d - 1 a ca. 2 - 40 a

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Defense against Radiation Damage

early effects

causes:

slowing-down and increasingly blocking of cell formation

defense:

up to doses of 250 mSv immediate compensation of cell loss by acceleration of cell division, shortening of cycle period

late effects and hereditary effects

causes:

structural damage of DNA

defense:

repair, cell elemination (apoptosis)

A health damage becomes manifest only if the defense systems fail.

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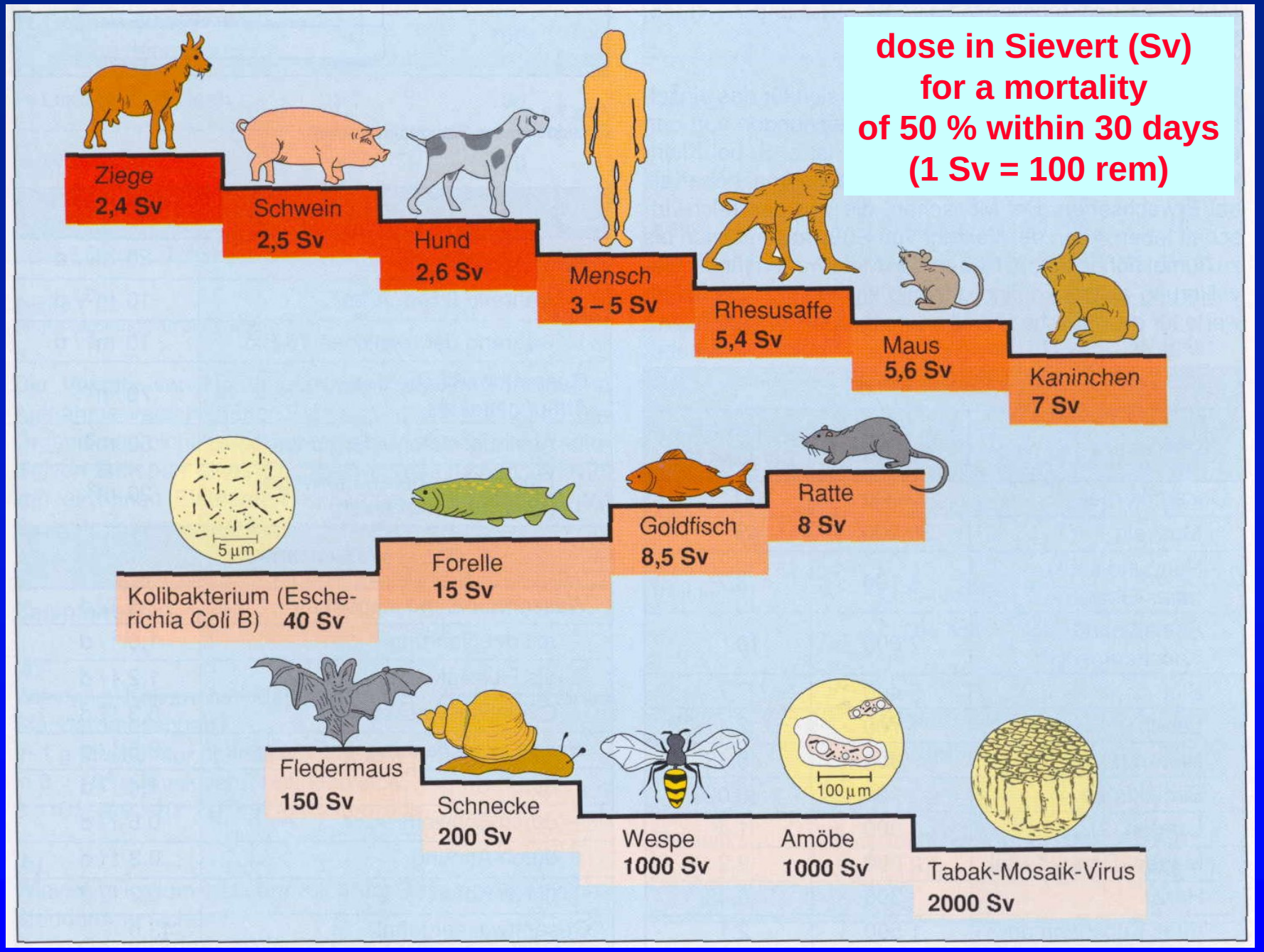

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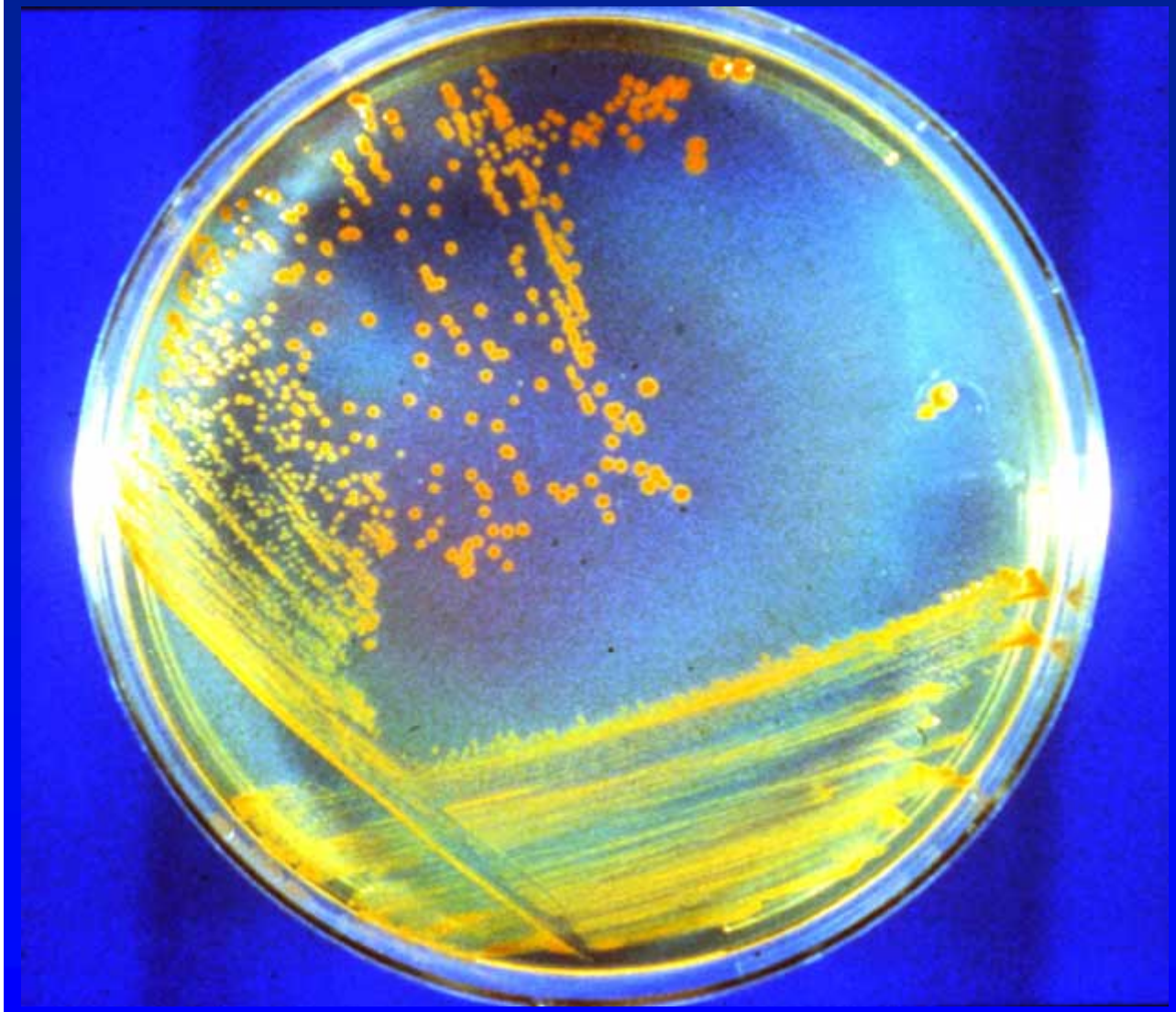
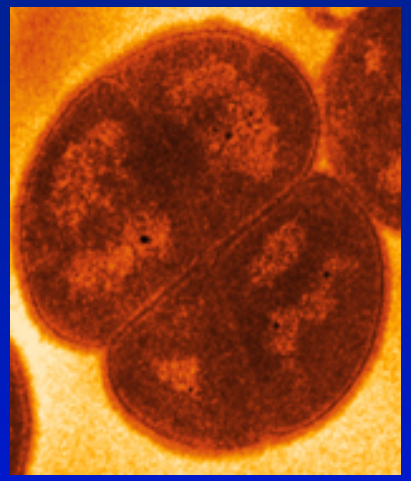
Deinococcus radiodurans





LD_{50} ~ 15 000 Gy

Fast and highly efficient repair of DNA damage within hours

4 – 10 copies of DNA molecules

www.microbe.org/microbes/deinococcus.asp

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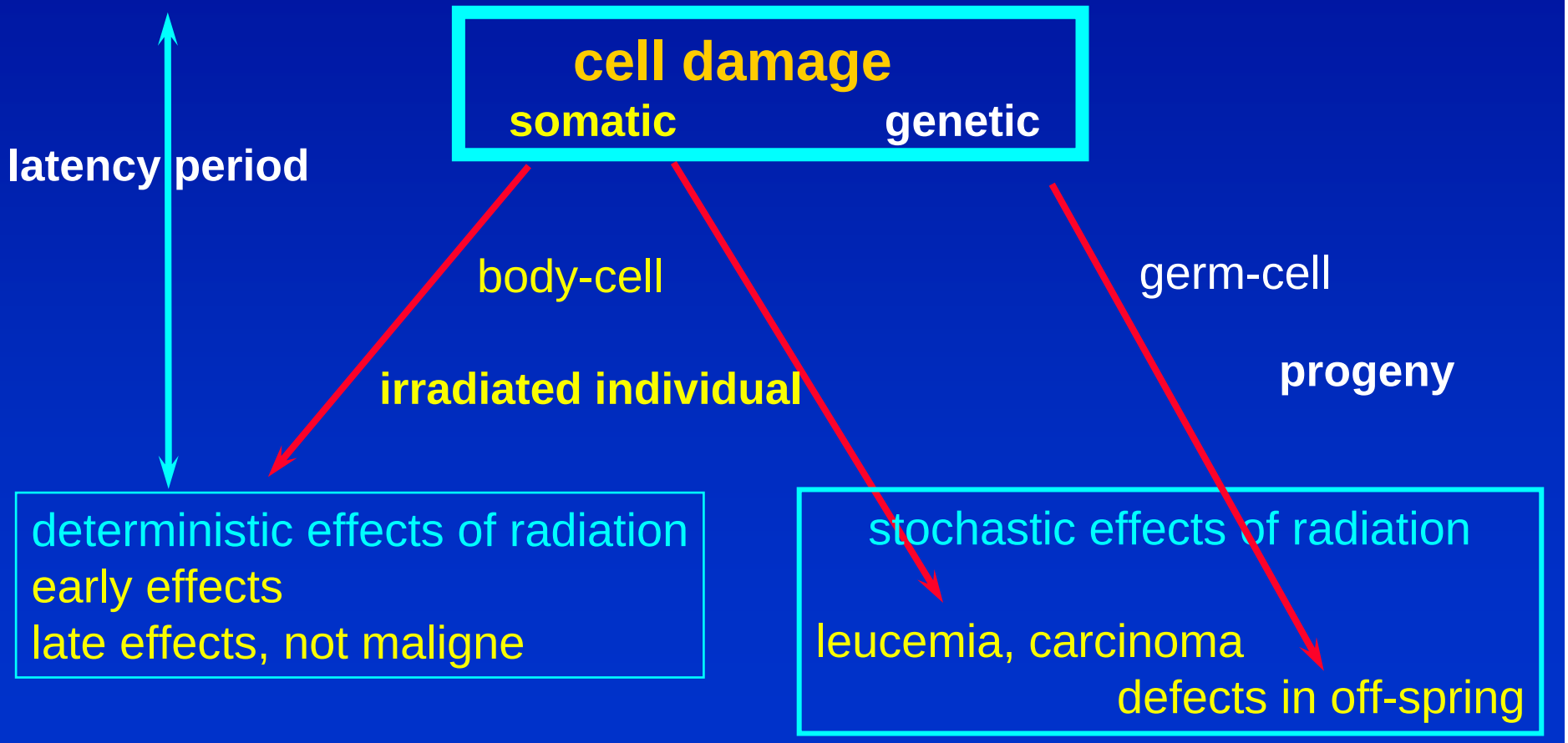
Biological Effects of Radiation



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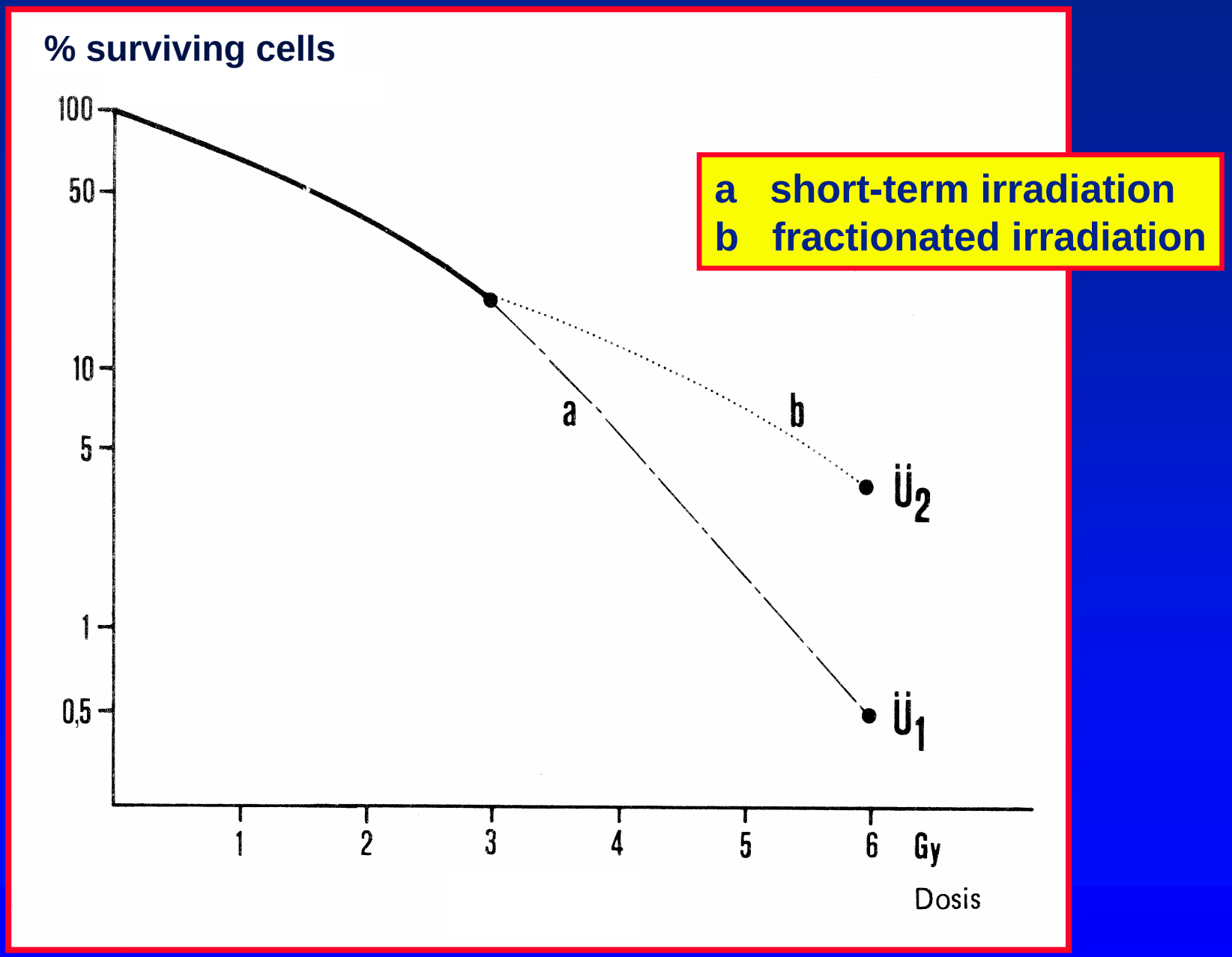
Dependencies of Radiation Effects

energy dose radiation quality	**The probability for defects at DNA increases with increasing dose and ionization density**
sensibility of tissue	**increases with increasing DNA-content, high for high cell proliferation rates**
milieu factors	**sensibilisation by chemicals (e.g. coffeine), other chemicals (e.g. zysteine) decrease the effect**
modifying factors	**smaller effect with fraactionation and protraction**
repair- und recovery processes	**efficient only for low-LET radiation , particularly efficient in strongly proliferating tissues**



Cells of mice in vitro

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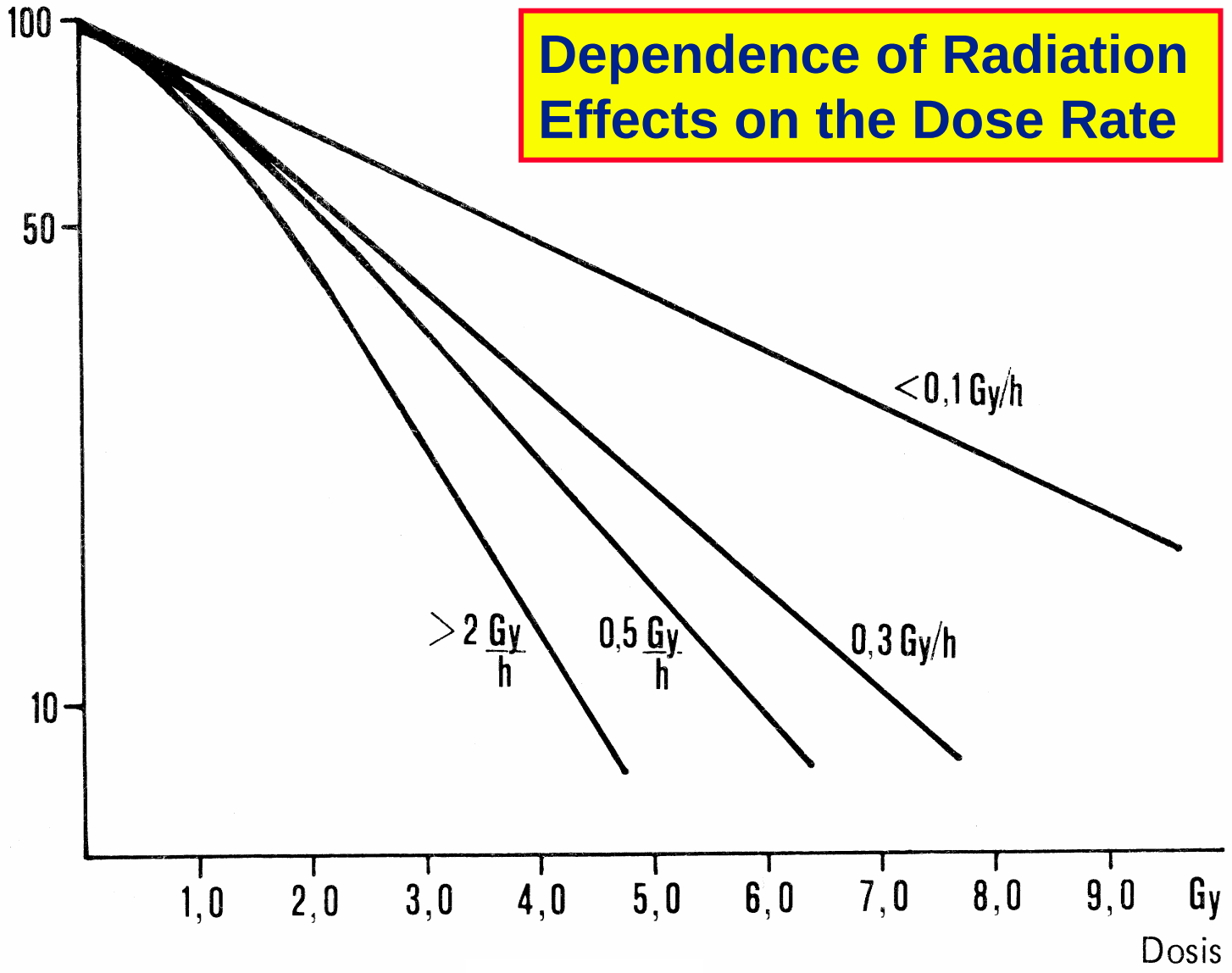
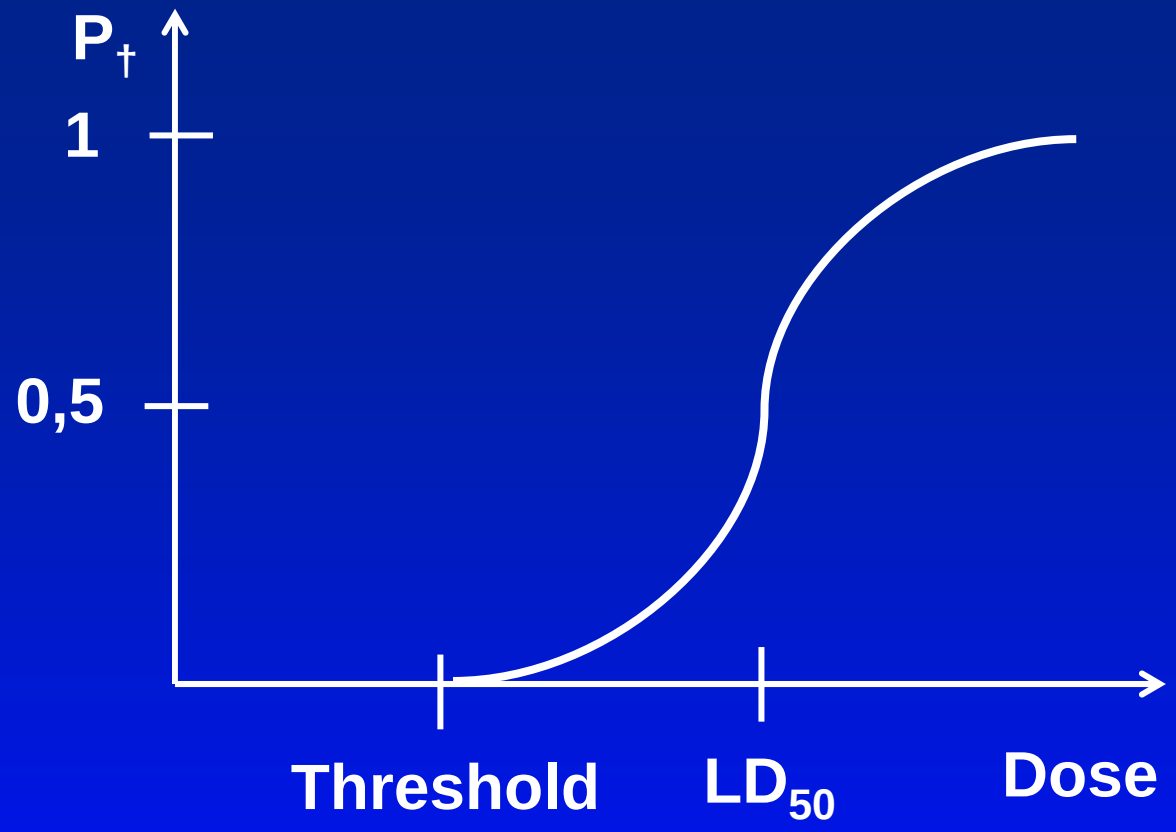
Dependence of Radiation Effects on the Dose Rate



Deterministic Effects



- Biological effects, for which the severety of the damage depends on the dose.
- Deterministic effects have a threshold dose.

(erythrema, radiation syndrome, cataracts of the eye lenses)

Threshold Doses for Clinical Effects in Man after Short-Term Partial-Body Irradiation

threshold value at which about 1 - 5% of the irradiated persons show an effecrt

dose in Gy	part of the body (type of damage/main symptoms)
2	bone marrow (atrophy); fetus (death)
3	testicles, ovary (permanent sterilization)
5	eye (cataracts); skin, 100 cm^2 (inflammation); head-hair (temporal falling-off)
10	head-hair, 10 cm^2 (permanent falling-off)
20	skin, 80 cm^2 (scaling off)
40	heart, lungs (inflammation)

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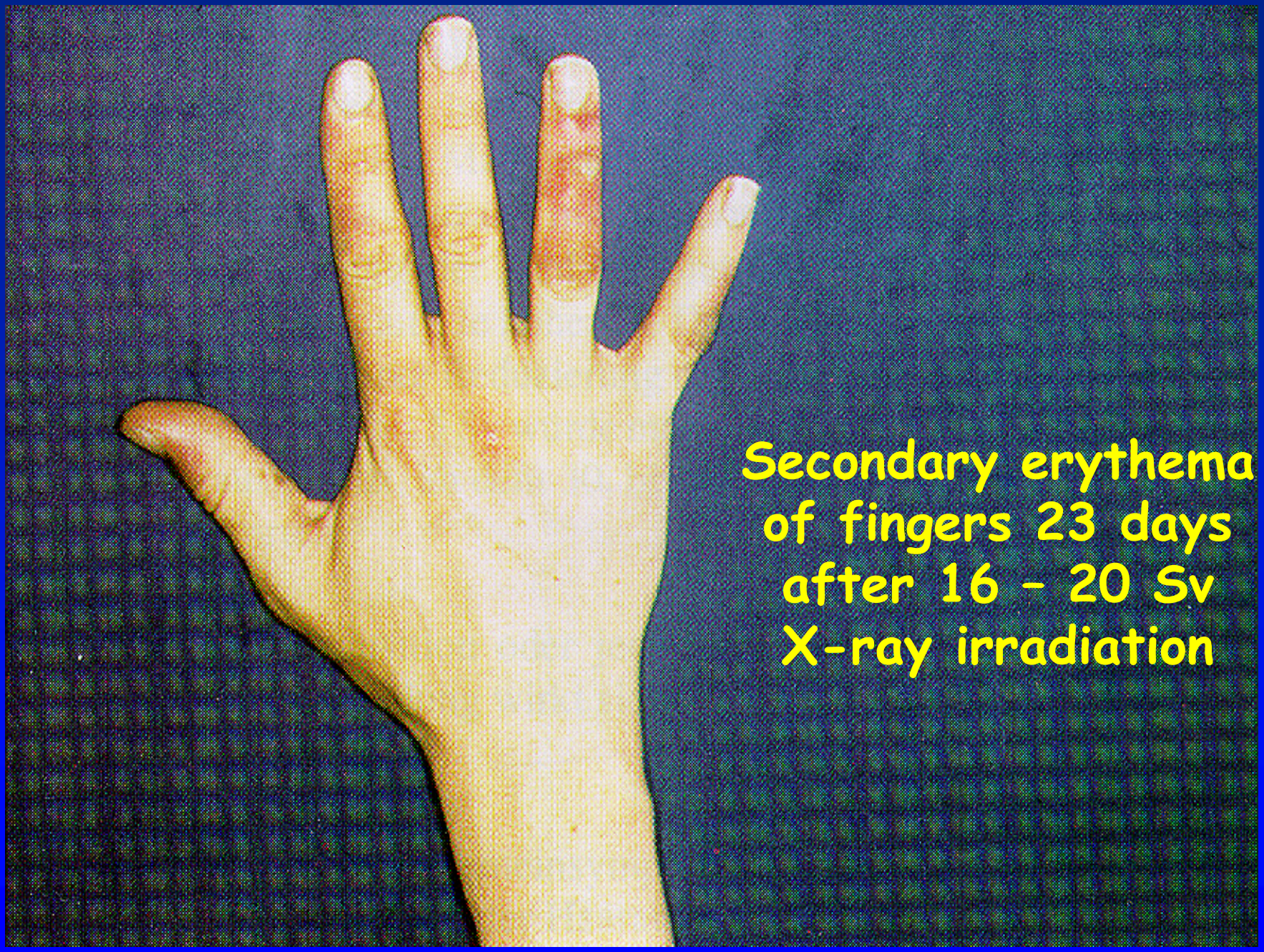

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Radiation accident 1944,

9 Sv on the right hand,

3 days after irradiation

Acute Radiation Syndrome (ARS) after Whole-Body Exposure

dose in Gy	latency period	main symptoms	organ	prog-nosis	lethal risk in %	death due to
0,2	-	threshold	-	very good	0	-
1	> 5 h	small changes of blood counts	bone marrow	very good	0	infections hemorrhage
1-2	> 3 h	decrease of leucocytes and thrombocytes	bone marrow	good	0-10	infections hemorrhage
2-10	0,5–2 h	heavy damage of blood counts	bone marrow	un-certain	0-90	infections hemorrhage
10-15	0,5 h	diarrhea, fever, electrolyte disorders	intestine	very bad	90-100	damage of intestine
> 50	min	spasms, coma	CNS	des-perate	100	edema of the brain

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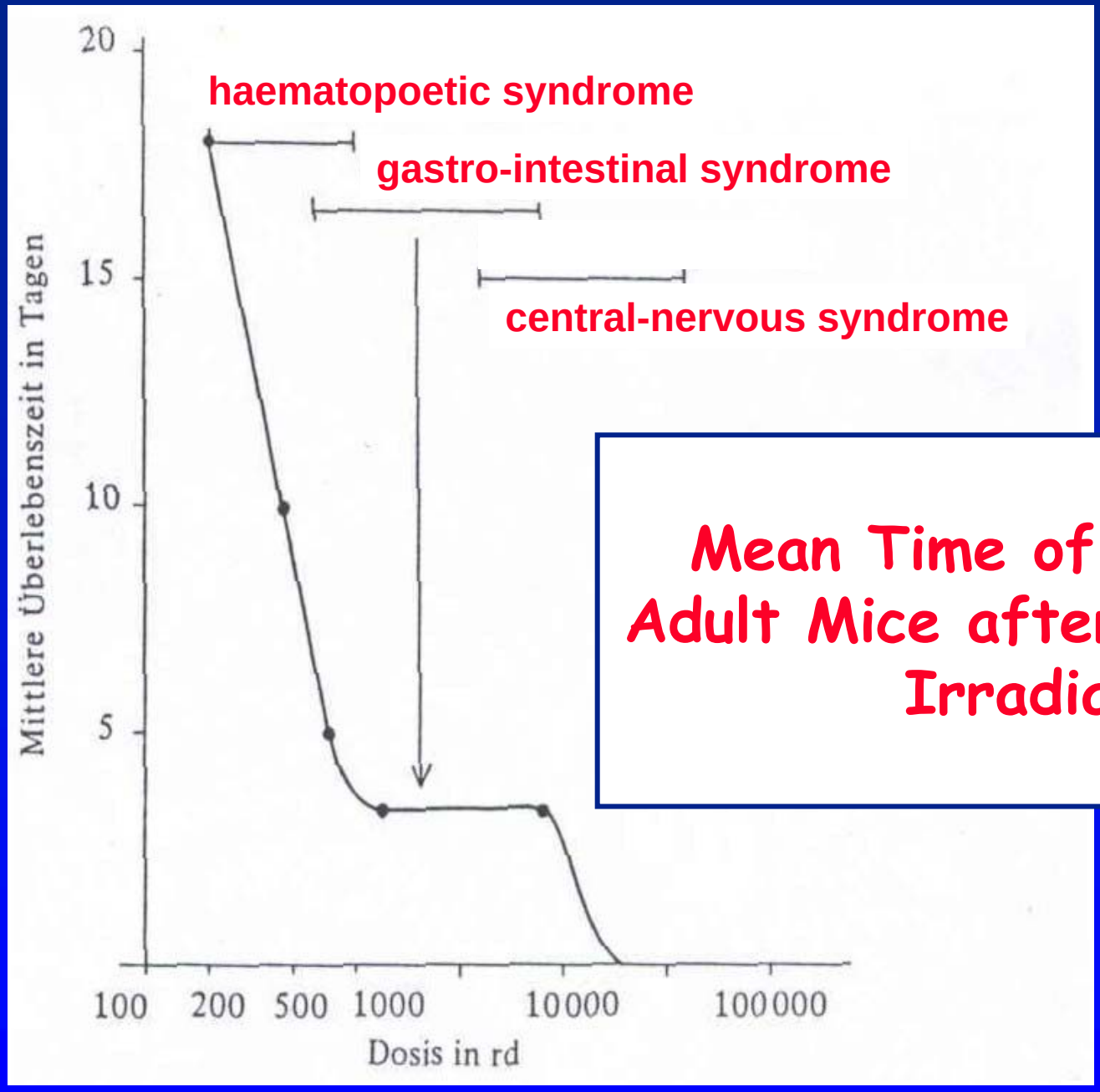


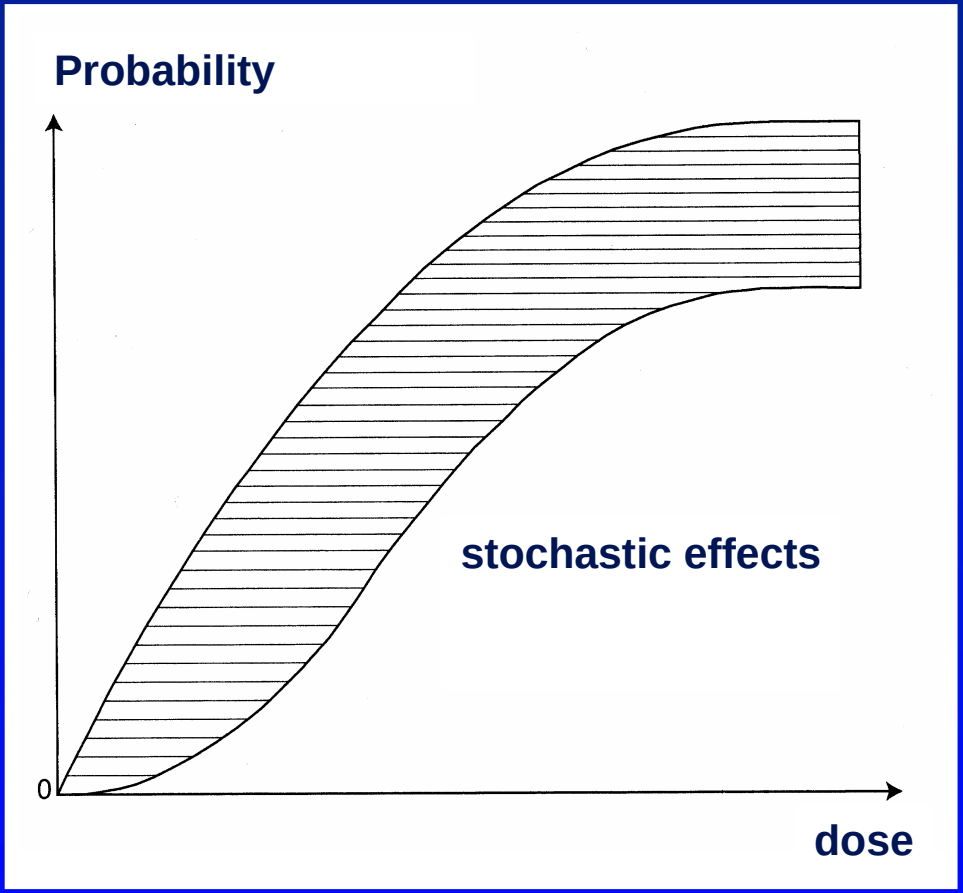
Mean Time of Survival of Adult Mice after Whole-Body Irradiation

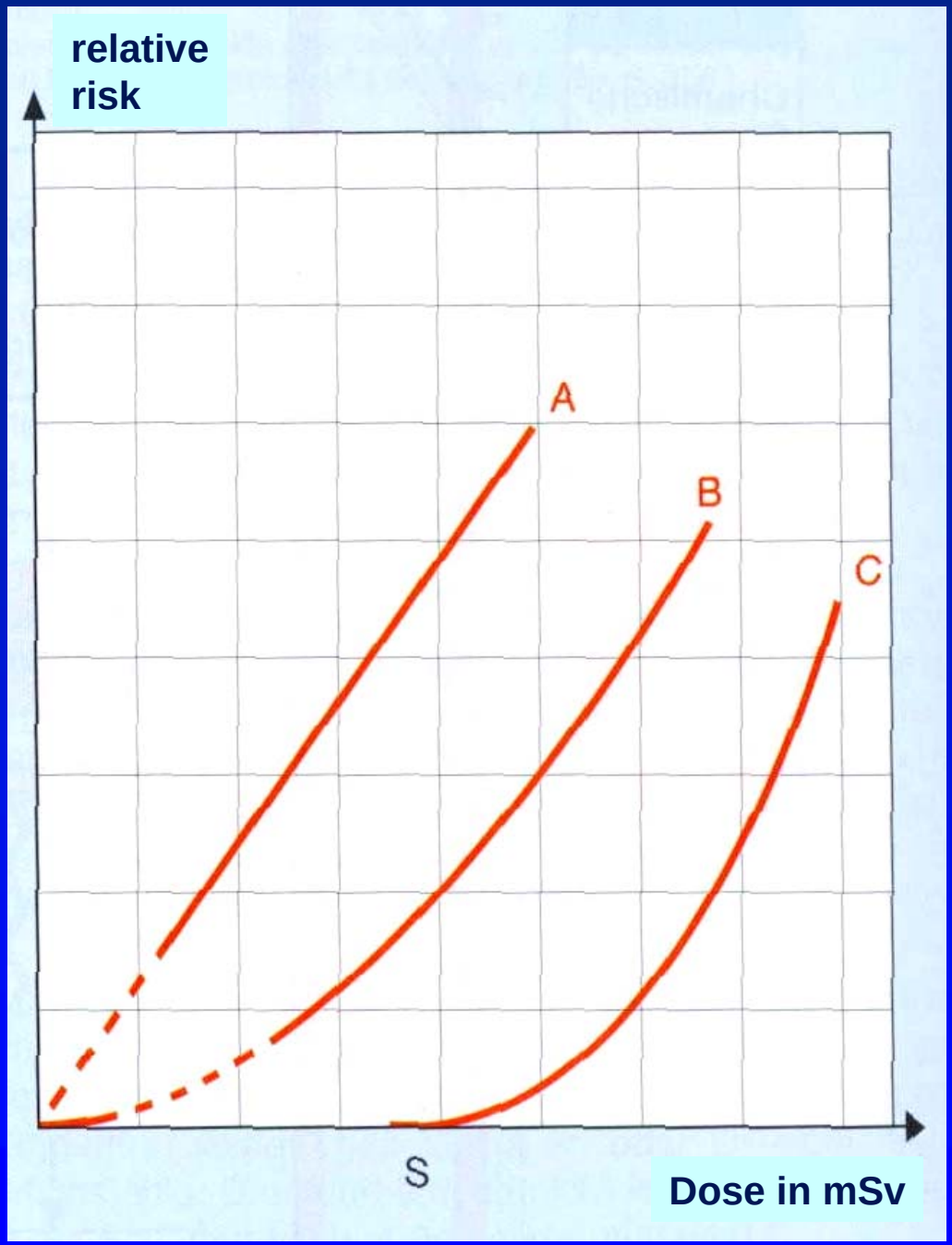
Cronkite und Fliedner, 1972

Stochastic Effects

Biological effects, for which not the severity of the disease depends on the dose, but the probability of their occurrence is a function of the dose without that a threshold might exist.

(carcinoma, leucemia, genetic defects)





Dose-Risk Curves for the Region of Higher Radiation Doses and Extrapolation into the Region of Small Radiation Doses

A: linear extrapolation
B: linear-quadratic extrapolation
C: dose-risk curve with threshold

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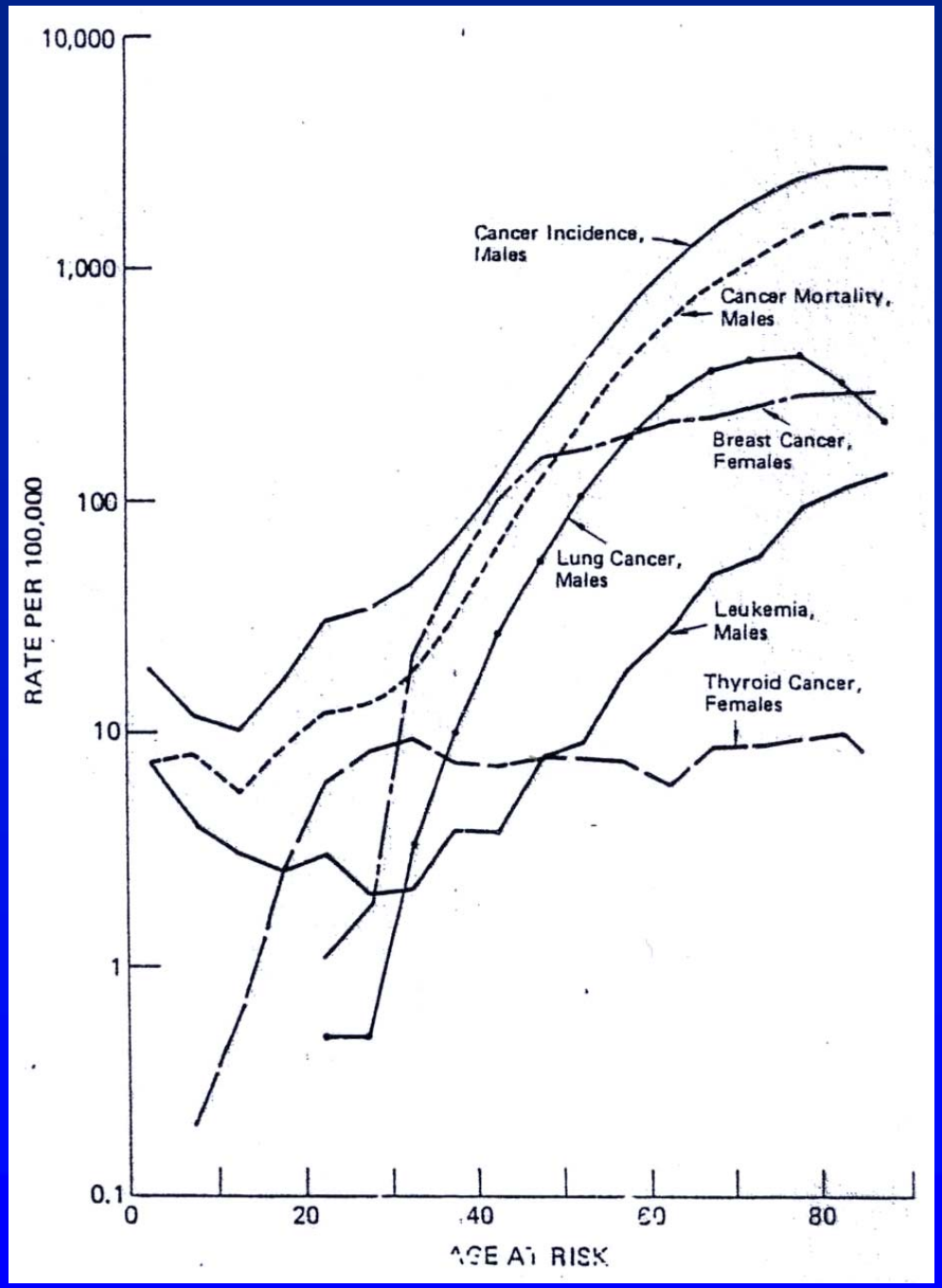

Spontaneous Incidence of Carcinomas

Age-Specific Mortality and Incidence in White US Citizens (without melanoma) [BEIR 1980]

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Death Probabilities

ICRP 60

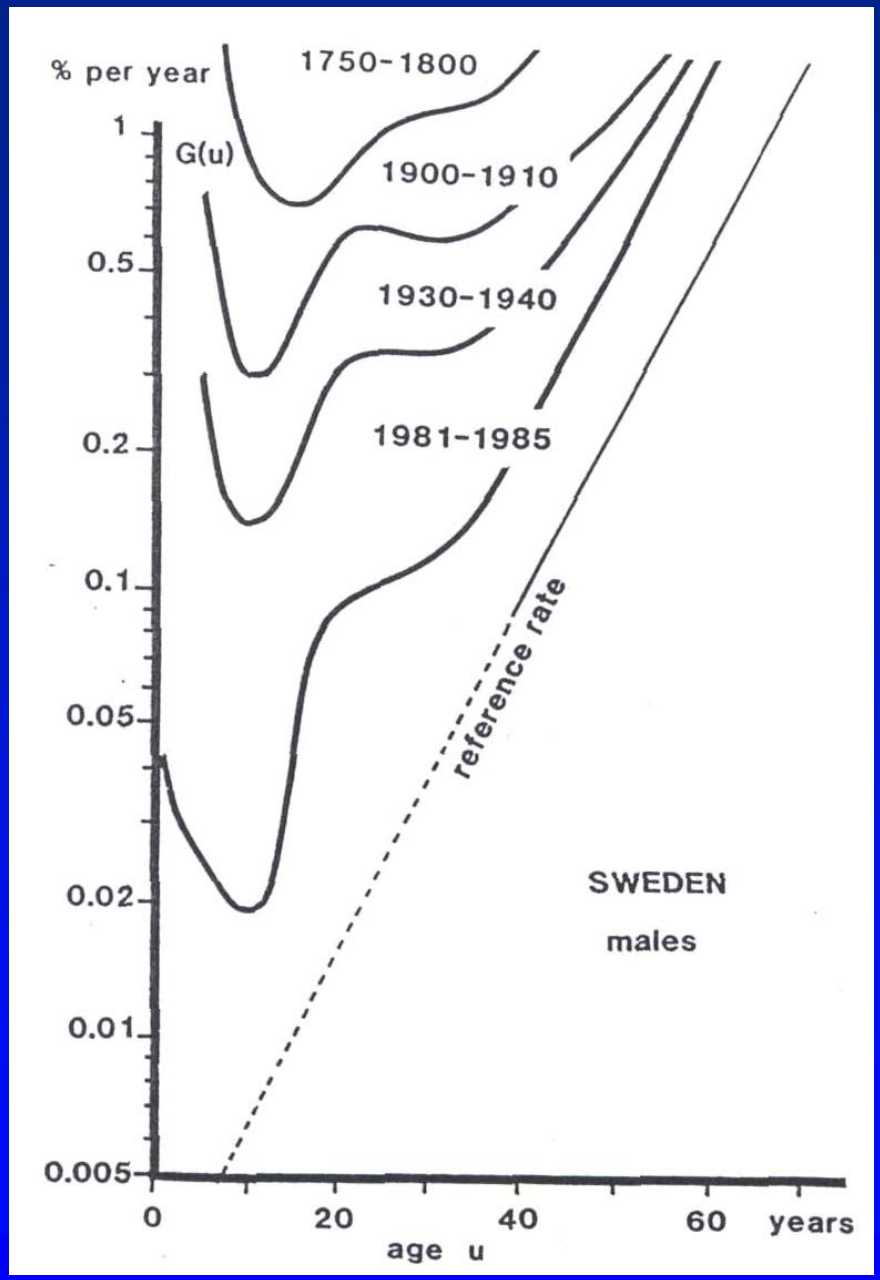

Fig. C-1. Gompertz-Makeham curves (the age-specific mortality rate) for Swedish males from 1750–1800 to 1981–1985. The "reference rate" is the lowest age-specific mortality rate currently found in any country for the various ages.

Death Rates in Sweden (ICRP 60)

age	$R_\dagger$ (natural) in a^{-1}
15	$2 \cdot 10^{-4}$
20	$1 \cdot 10^{-3}$
40	$2 \cdot 10^{-3}$
60	$1{,}2 \cdot 10^{-2}$
80	$7{,}1 \cdot 10^{-2}$
100	$42{,}7 \cdot 10^{-2}$
	$R_\dagger$ (occupational) in a^{-1}
mean occupational	$1{,}1 \cdot 10^{-4}$
mean travel to work	$0{,}73 \cdot 10^{-4}$

Occupational Death Risks

occupation	$R_\dagger$ in a^{-1}
trade	$0{,}72 \cdot 10^{-4}$
fabricatioon	$0{,}93 \cdot 10^{-4}$
services	$1{,}2 \cdot 10^{-4}$
administration = mean in Germany	$1{,}3 \cdot 10^{-4}$
transport	$3{,}8 \cdot 10^{-4}$
agriculture	$6{,}5 \cdot 10^{-4}$
buidling and construction	$7{,}4 \cdot 10^{-4}$
mining	$1{,}2 \cdot 10^{-3}$
free time, household	$2{,}3 \cdot 10^{-4}$
traffic, air traffic cars 25 min/d, planes 1 h/week	$2{,}4 \cdot 10^{-4}$

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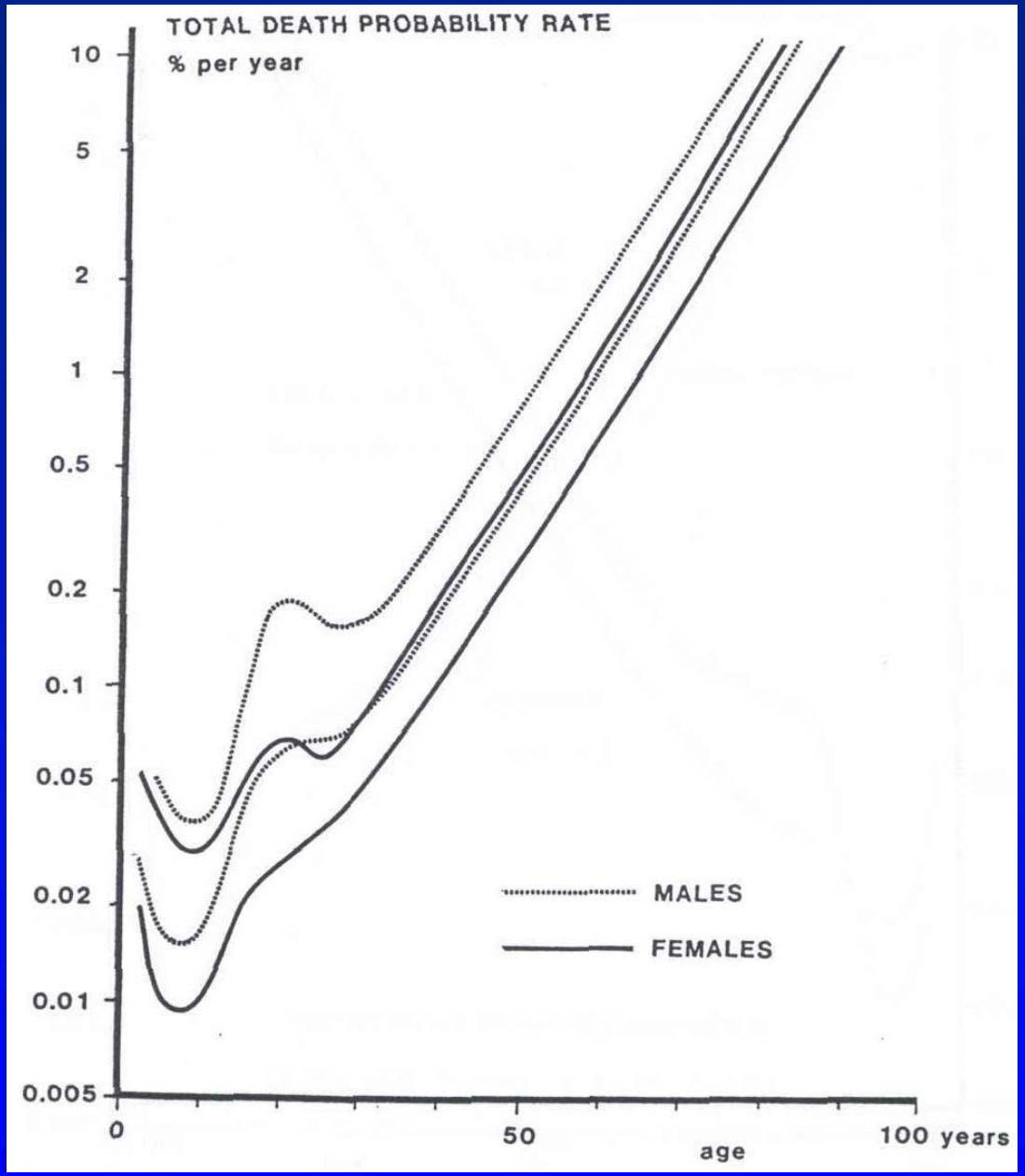
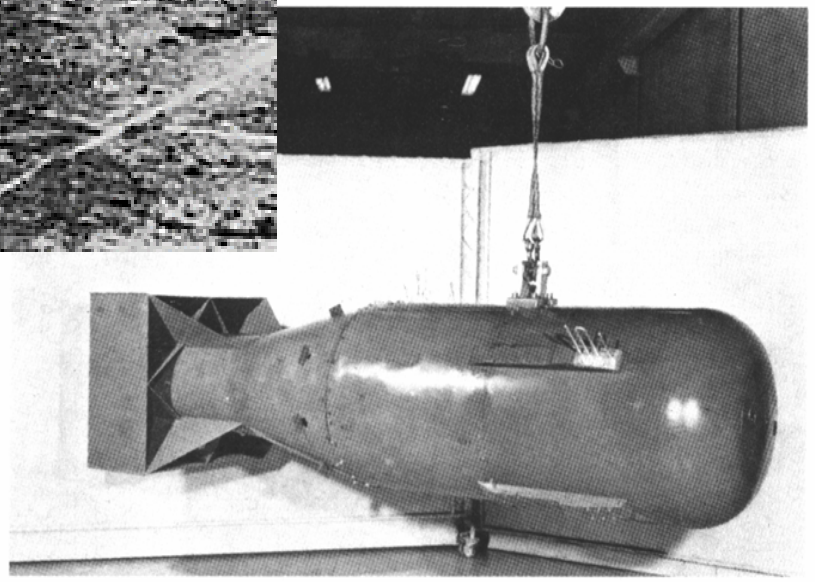
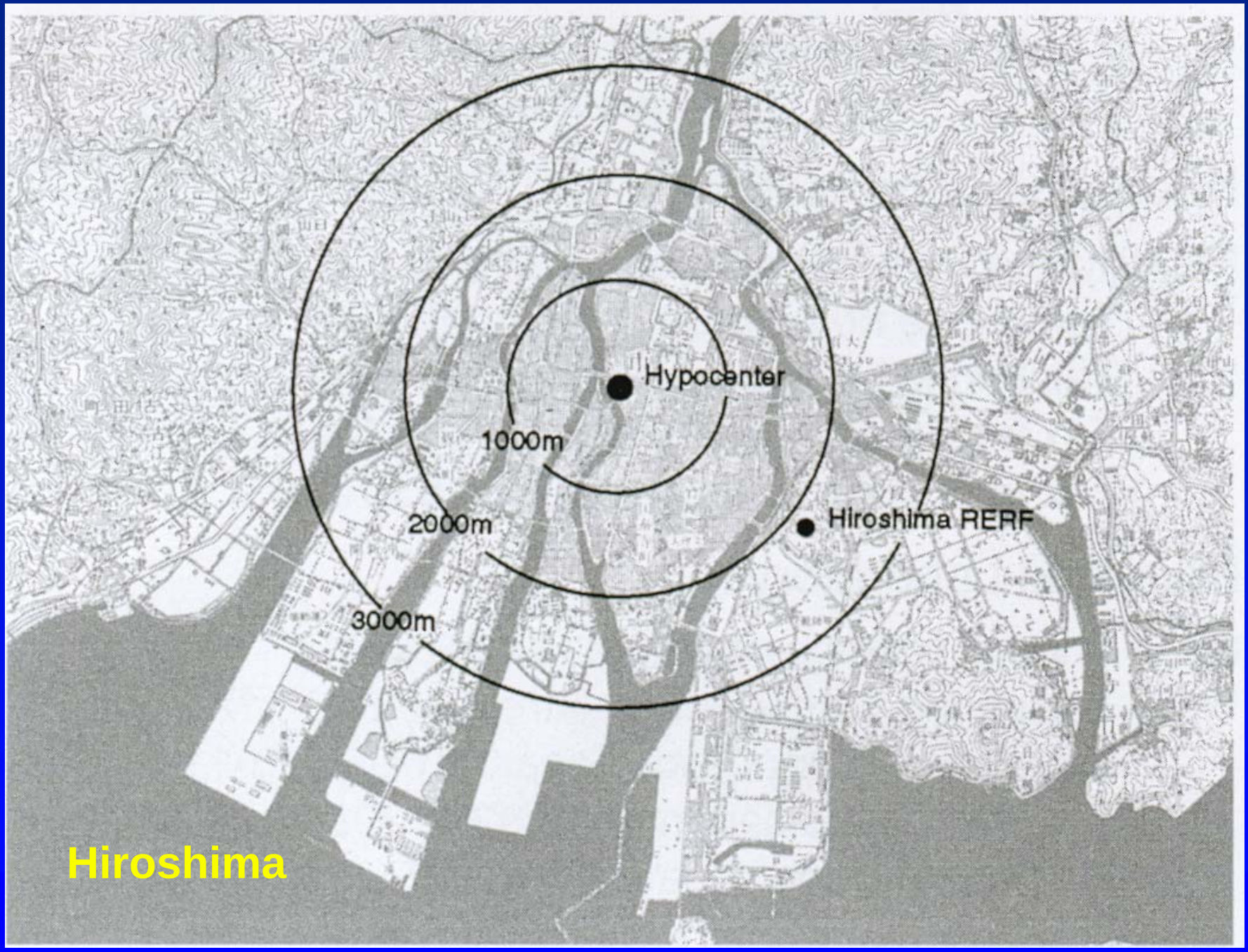


Fig. C-6. Variation (extreme values) of the age-specific mortality rate, approximating the conditional death probability rate, for 18 industrialised countries usually considered "safe": Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany (GDR), Germany (FRG), Italy, Japan, the Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom and USA.

Hiroshima



- 6th August 1945
- U-235 as fissile material
- Beryllium-Polonium-ignition
- 20 kT TNT-equivalent



Hiroshima

Hiroshima

Acute Health Effects of A-Bombs
Estimates of Early Deaths and Injuries
(August - December 1945)

	Hiroshima	Nagasaki
population	360 000	250 000
death	140 000	70 000
injuries	80 000	80 000

Stochastic late effects of the atomic explosions in Hiroshima and Nagasaki

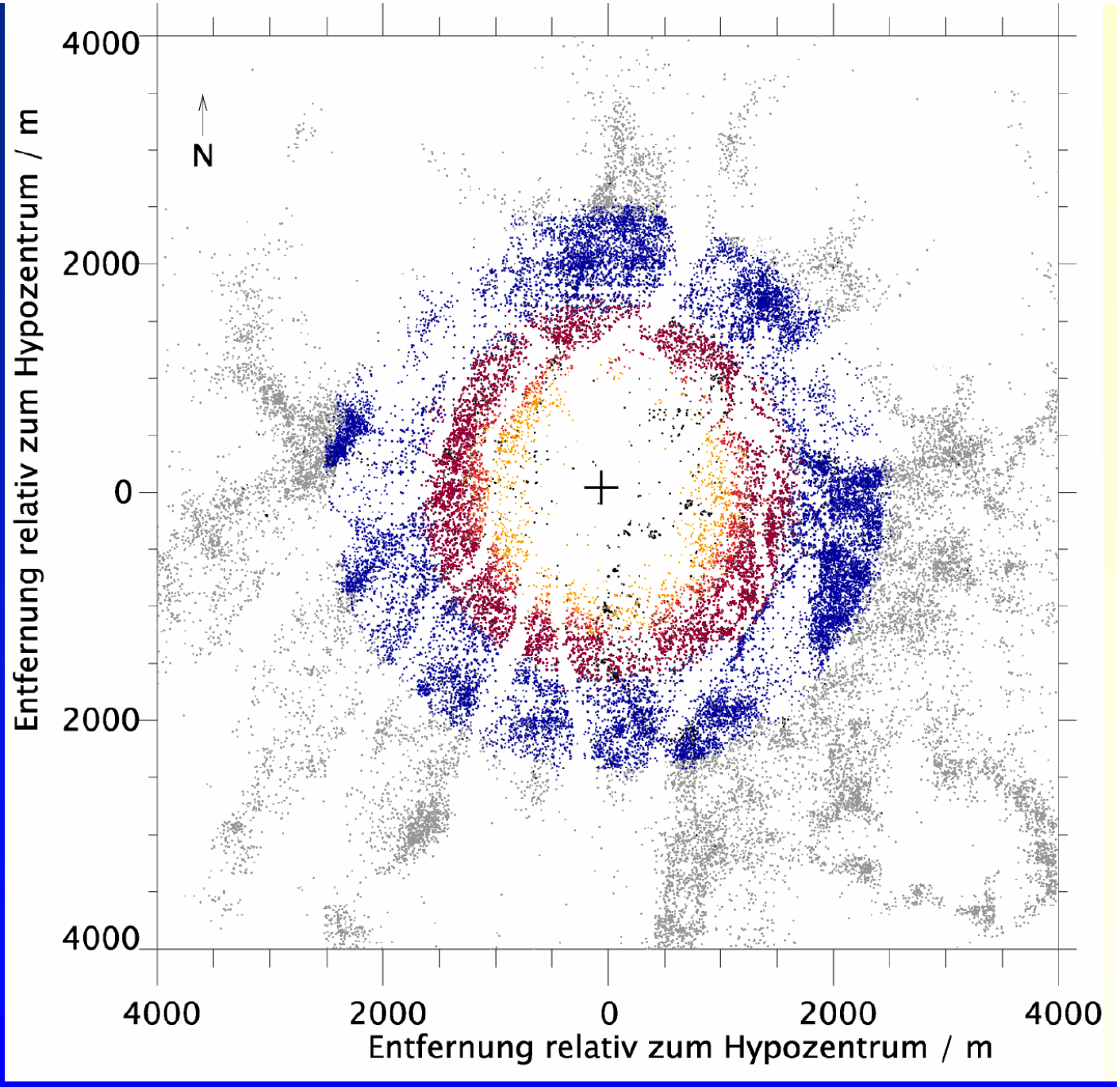
Life Span Study
(LLS-DS86) **120 321 persons**

davon **26 517 „not in city“**
2 383 no dose
193 unknown destiny

86.611 survivors with dose estimates (DS02)

surviving (1950 – 2000) **45 %**
deaths (1950 – 2000) **55 %**

Hiroshima: colon doses acc. to dosimetry DS86



W. Rühm, Physik Journal 2/12 (2003) 37

Public Opinion

250 000 late effects in Hiroshima due to radioactive radiation.

German Radio NDR 3
on the 50. Anniversary of the Atomic Bombing

Epidemology

1950 – 2000 additional cases of leukemia: 93
additional solid cancers: 479

Stochastic late effects of the atomic explosions in Hiroshima and Nagasaki

1950 – 2000:

Total number of deaths: 47.685

	296 leukemia
among them	93 due to radiation
	10.127 solid cancers (without leukemia)
among them	479 due to radiation
sum	10.423 solid cancers plus leukemia
among them	572 due to radiation
i.e.	21,9 % of all death due to cancer
	5,5 % of all cancer death due to radiation
	1,2 % of all death due to radiation

Preston et al., Radiation Research 162 (2004) 377 -389

S. Nagataki, RERF, 10th Congress of IRPA, Hiroshima, 2000

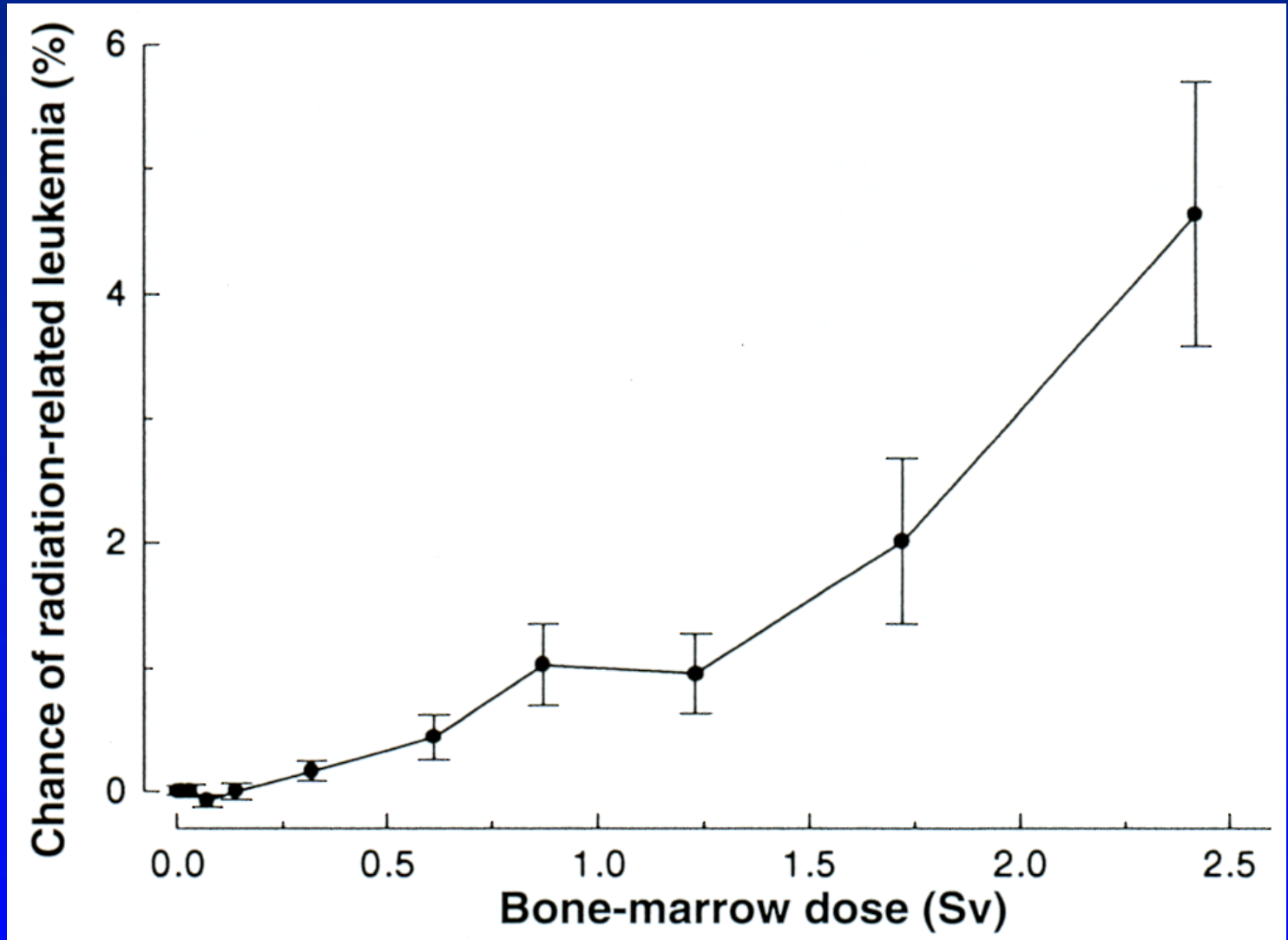


Figure 3. Radiation dose and leukemia incidence in the atomic bomb survivors, 1950-1990

S. Nagataki, RERF, 10th Congress of IRPA, Hiroshima, 2000

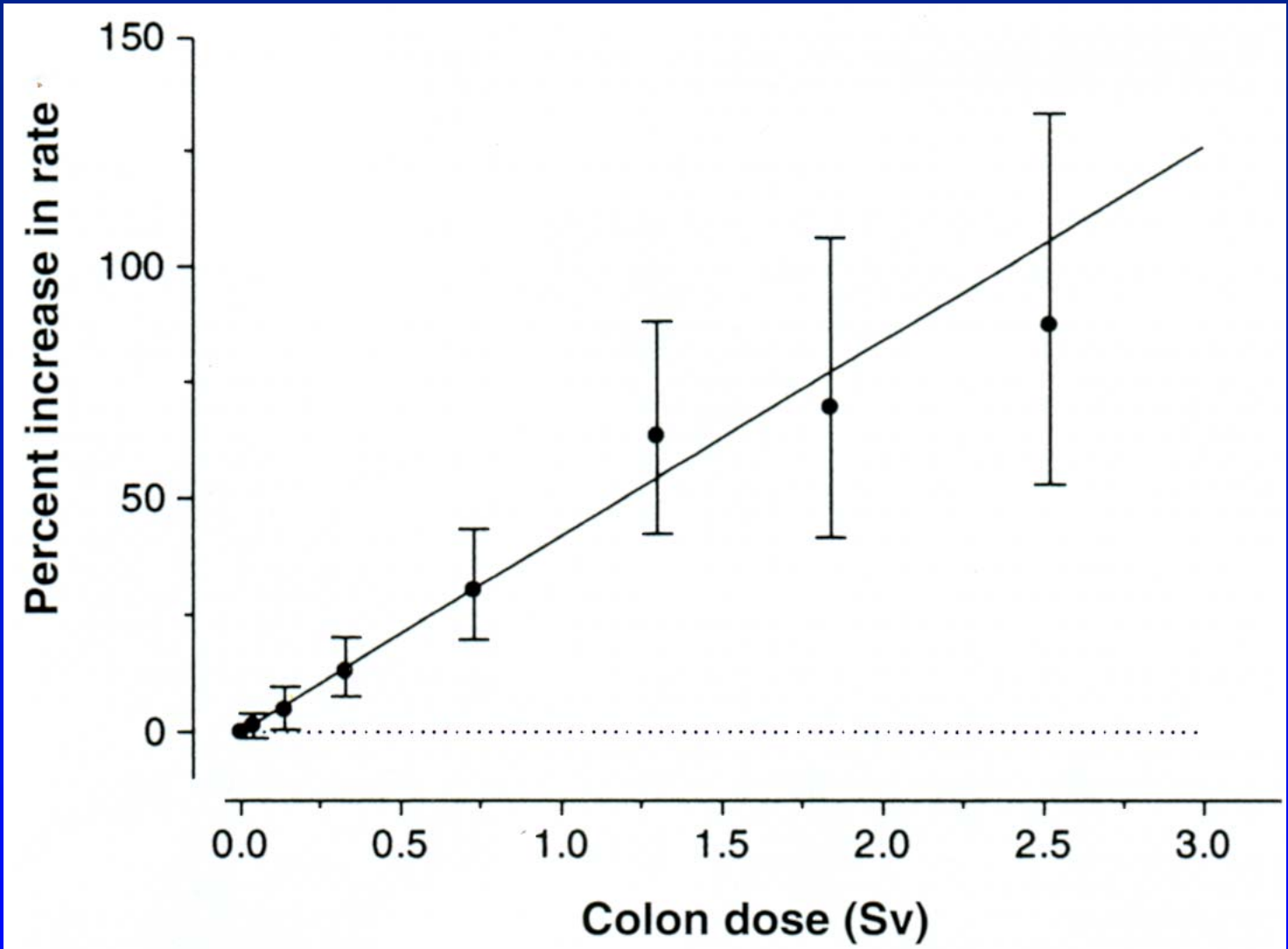


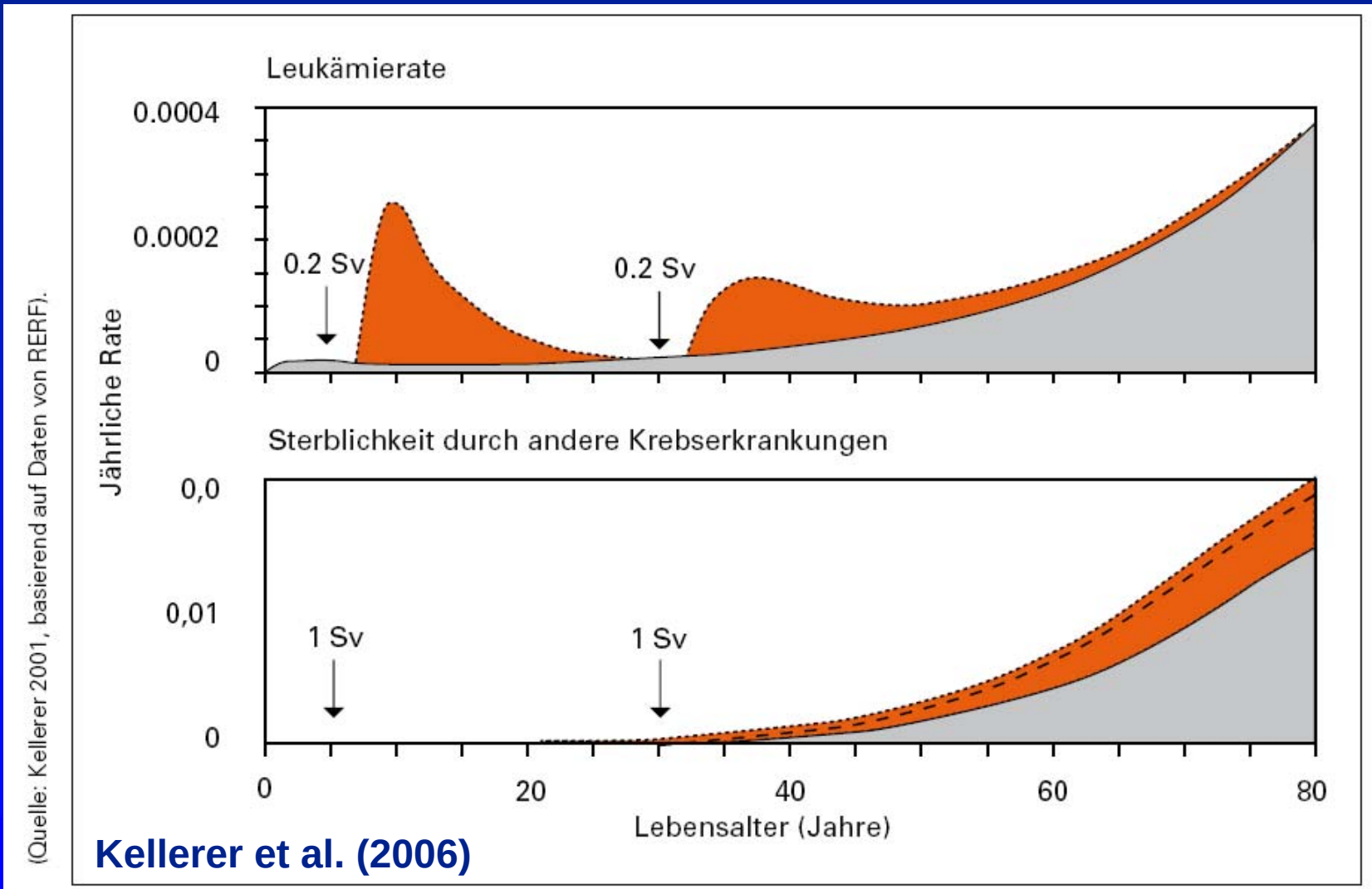
Figure 2. The effect of radiation on solid cancer risks in the atomic bomb survivors—dose response, 1958-1987

LSS Solid Cancer Dose Response

- No evidence of departure from linearity over the 0 - 4 Sv range; **risk 5 % Sv^{-1}**.
- Significant trend over the 0 - 0,2 Sv range.
- Estimated threshold is essentially 0.
- Upper 95 % confidence limit for the threshold is less than 0,1 Sv

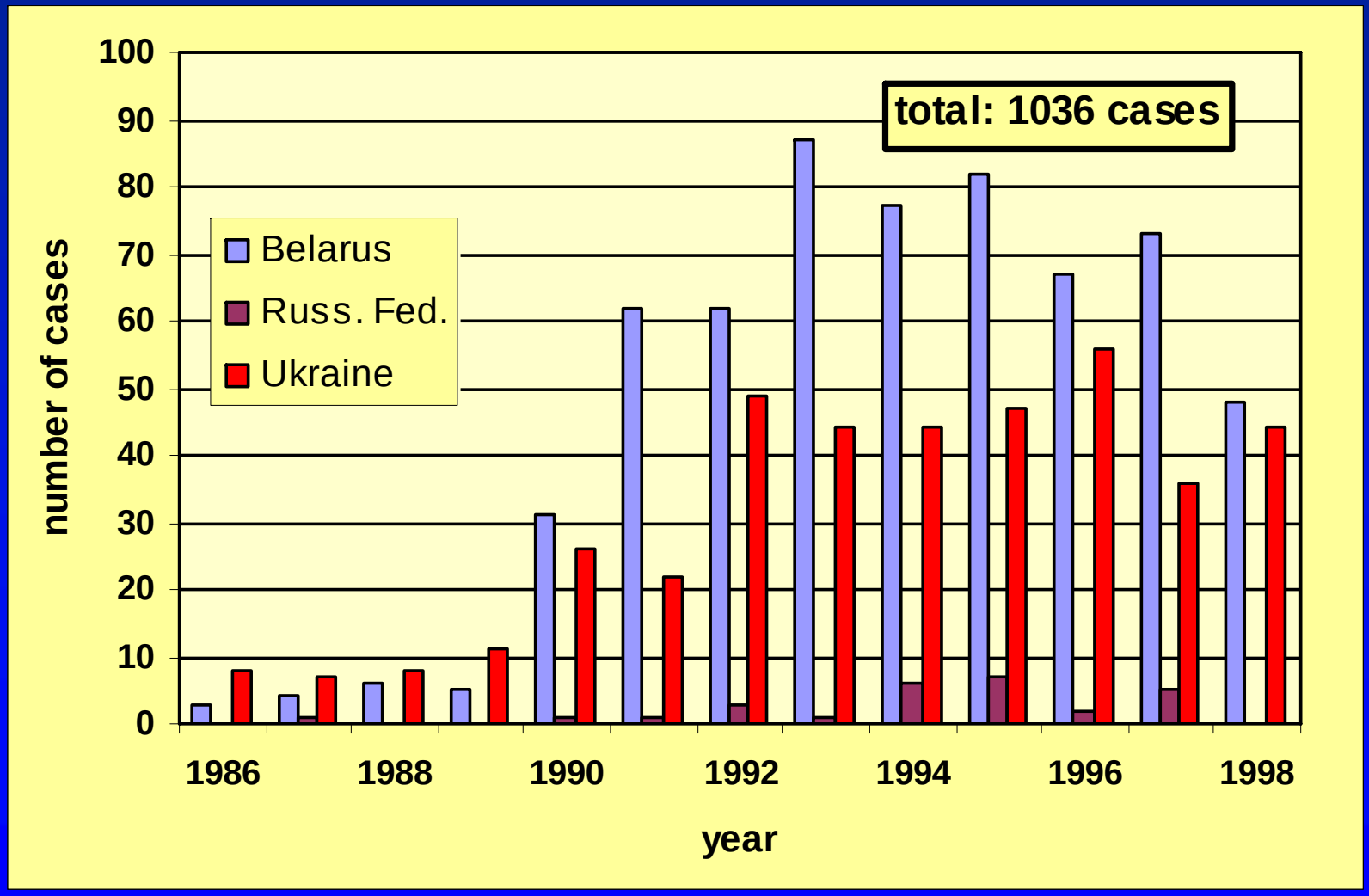
- No significant trend over the 0 - 0,05 Sv range.
- There is, however, no significant difference from the linear trend over the full dose range.

Dependency on age of leukemia incidence and mortality due to other cancers among the survivors of Hiroshima and Nagasaki



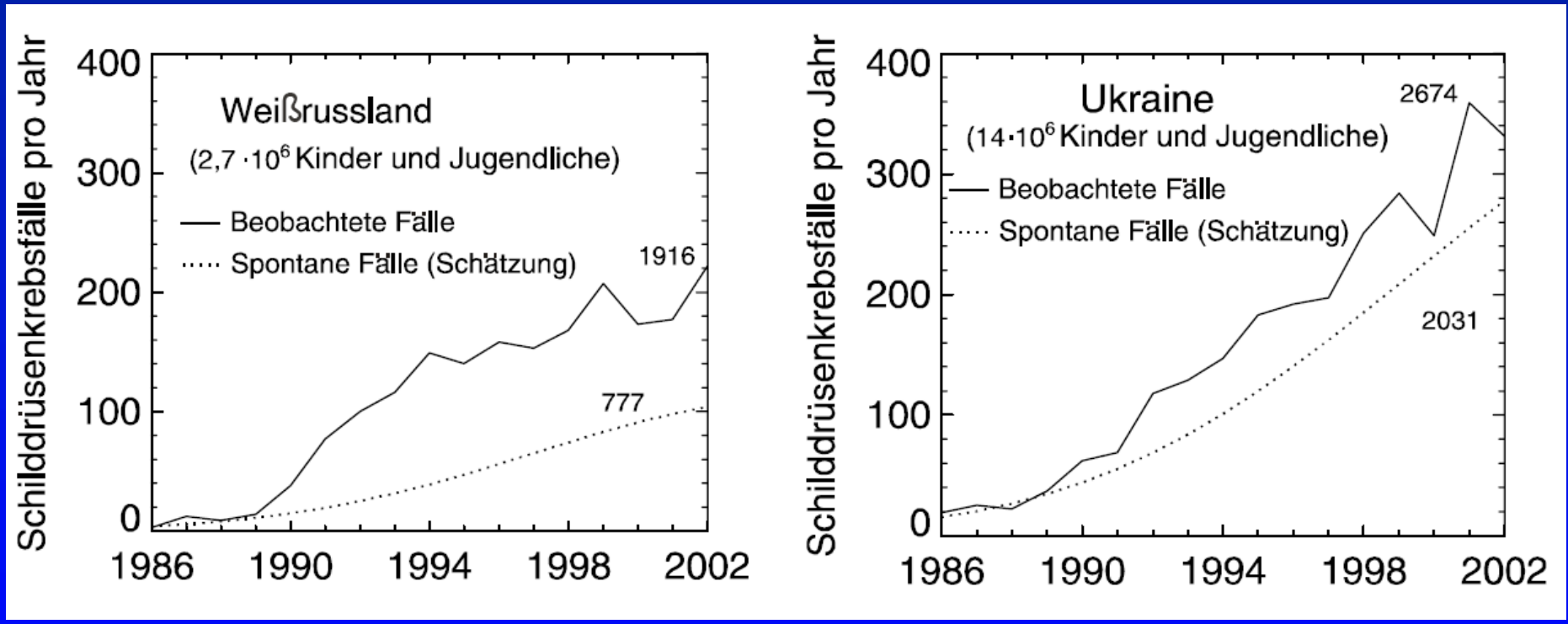
Kellerer et al. (2006)

Thryroid Cancer in Children under 15 Years Old (UNSCEAR, 2000)

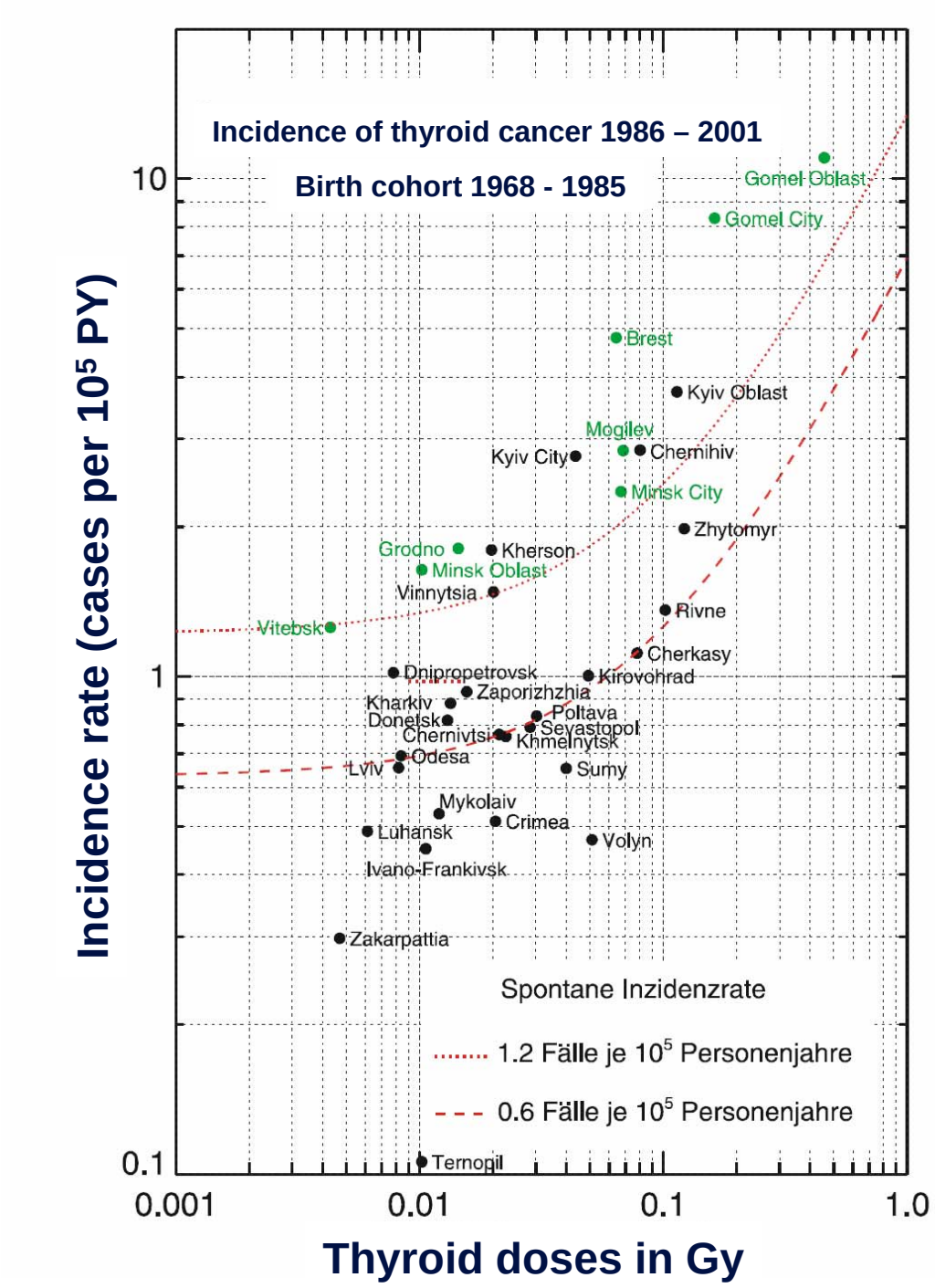


UNSCEAR (2000)

Annual and total numbers of thyroid cancer surgeries between 1986 and 2002 for those, aged 0 to 18 years old at the time of the accident (Jacob et al. 2005).



R. Michel, ZSR, Leibniz Universität Hannover



Mean thyroid doses of children and adolescents due tot he Chernobyl accident and incidence rates of thyroid cancer between 1986 and 2001.

The red lines represent a relative risk of 10 Gy^{-1} for two assumed spontaneous incidence rates.

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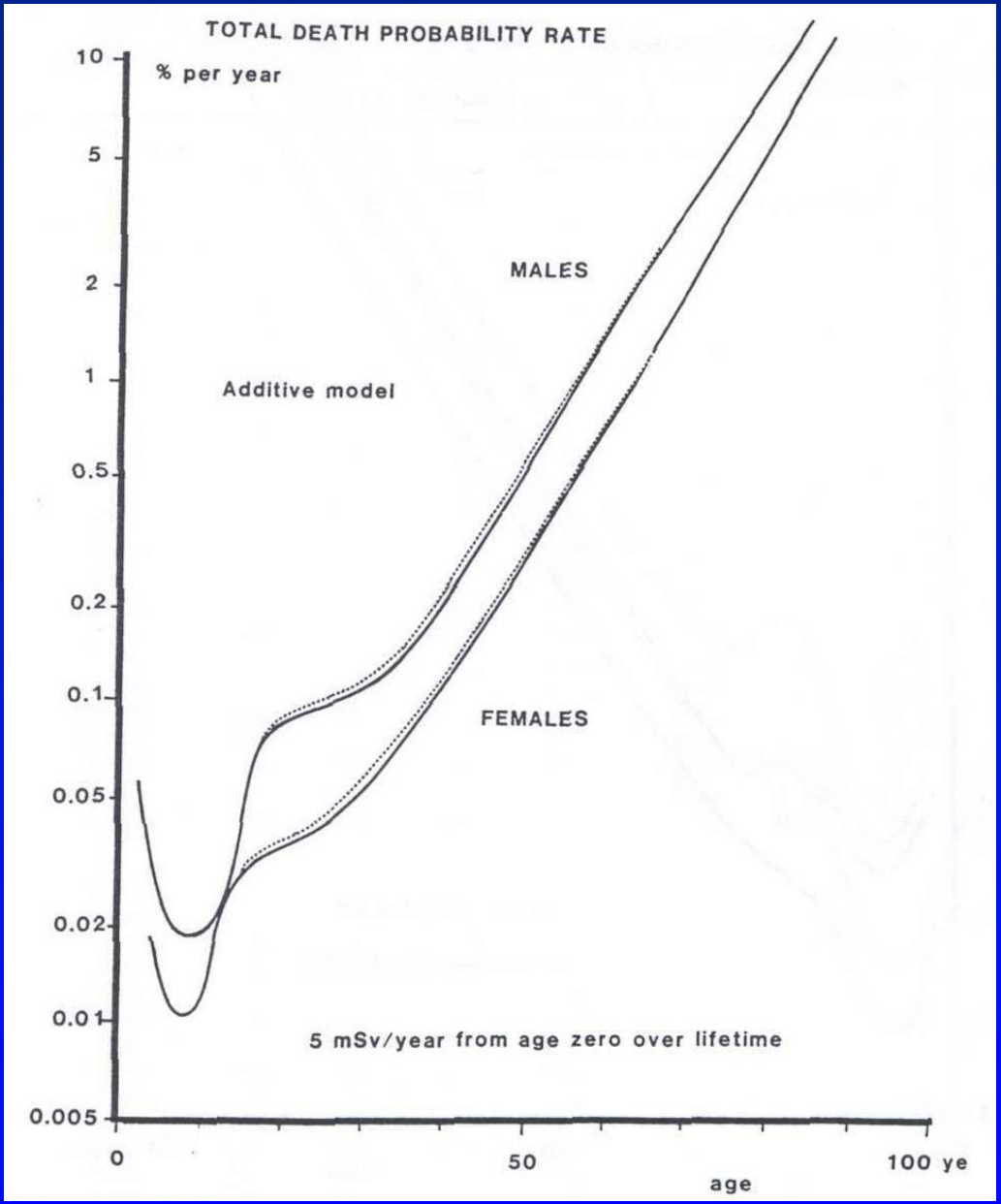

Fig. C-7. Change in the total conditional death probability rate (reference: the Swedish population 1986) after an exposure of 5 mSv per year from birth over lifetime, assuming a DDREF of 2. The change is only shown for the additive projection model. With the multiplicative model the change is smaller for ages below 50 years. At higher ages it is less than 4.5% for females and less than 2.5% for males; these changes are too small to illustrate in this diagram.

Exposure
5 mSv/a
over a lifetime

ICRP 60

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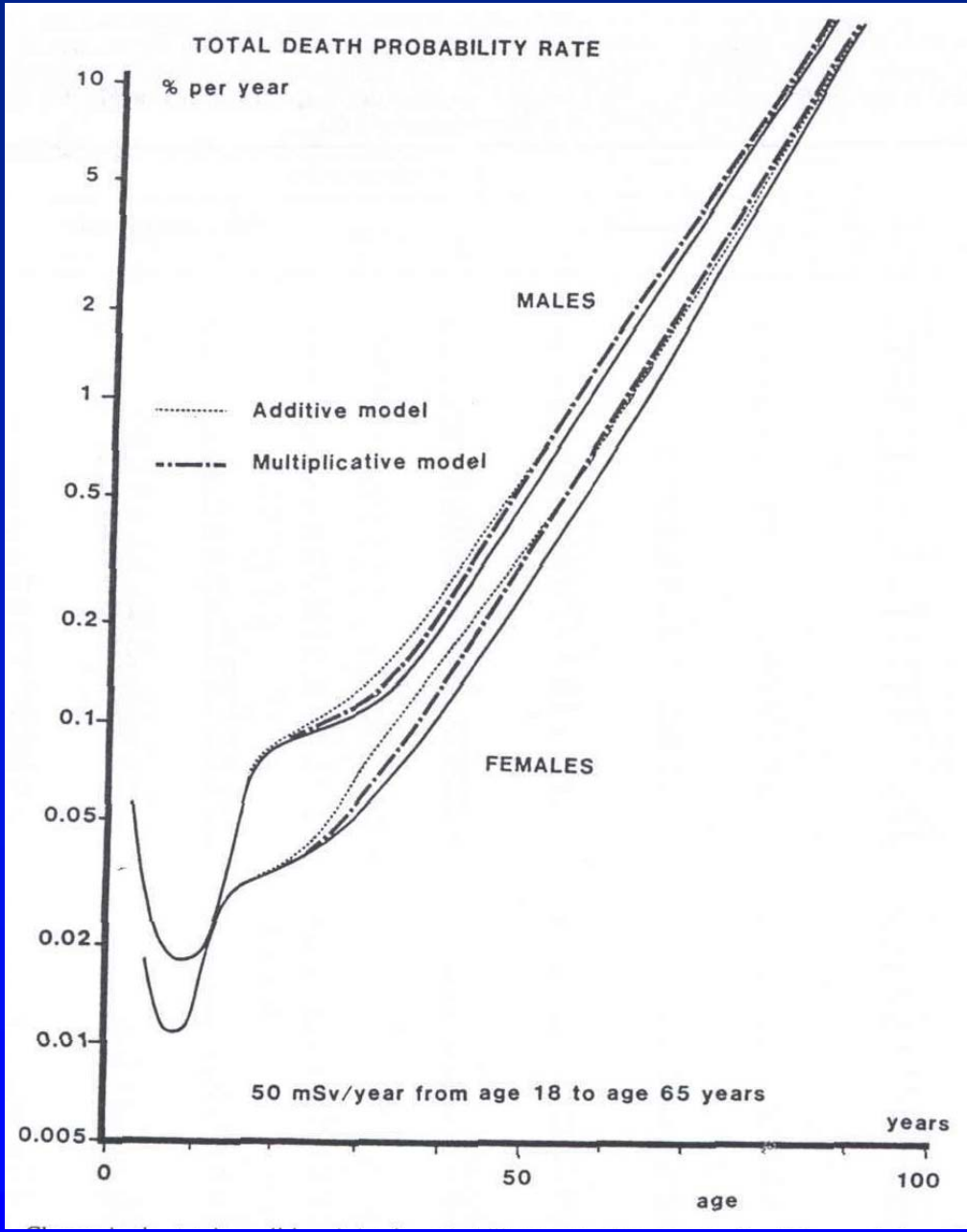

Fig. C-8. Change in the total conditional death probability rate (reference: the Swedish population 1986) after an exposure of 50 mSv per year from age 18 to age 65 years, assuming a DDREF of 2. The change is shown for each of the two projection models.

Occupational Exposure 50 mSv/a from age 18 to 65

ICRP 60

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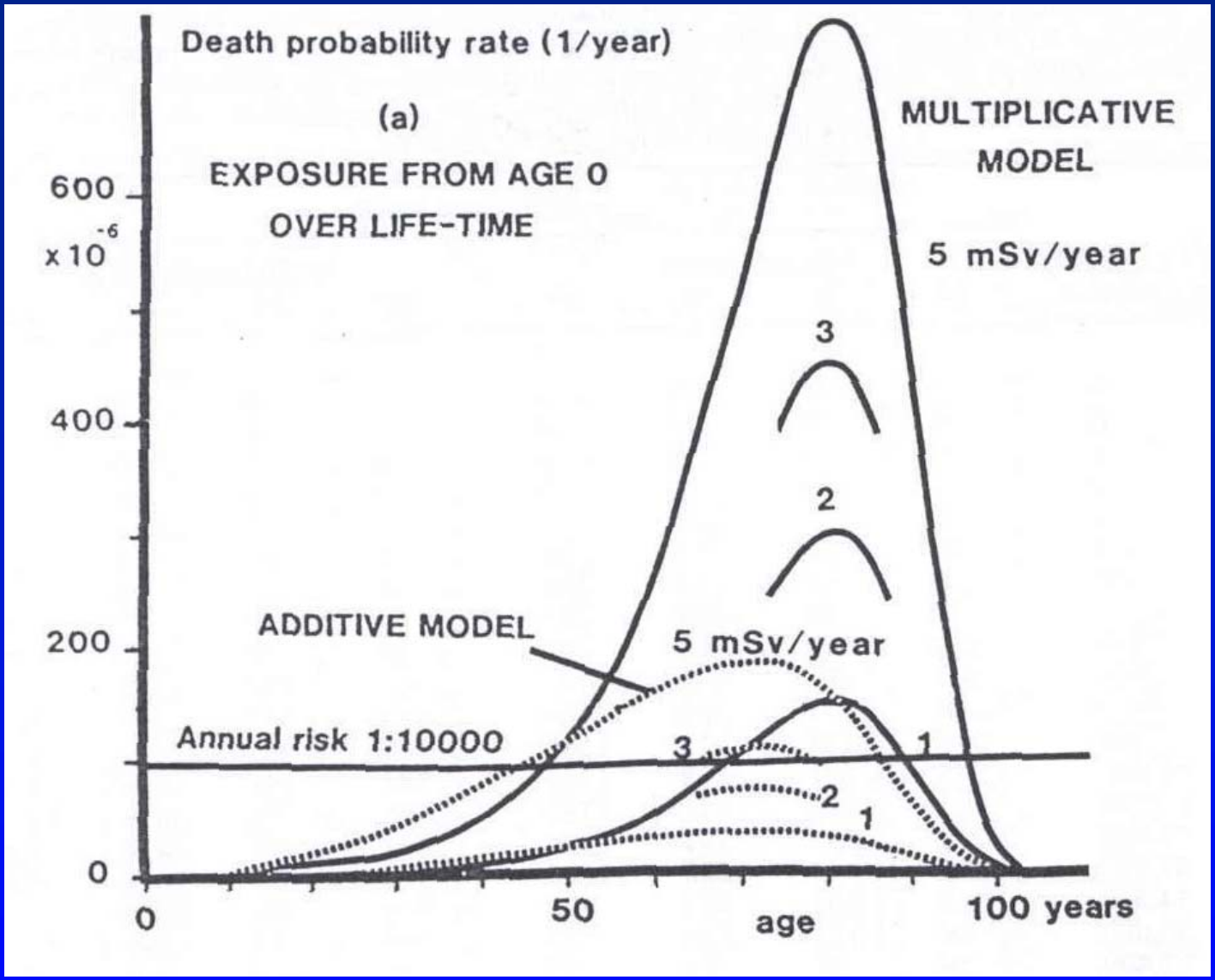


Fig. C-9. The unconditional death probability rate (the attributable probability density of the age of death, normalised for lifetime risk) for two exposure situations: (a) exposure from birth over lifetime, and (b)

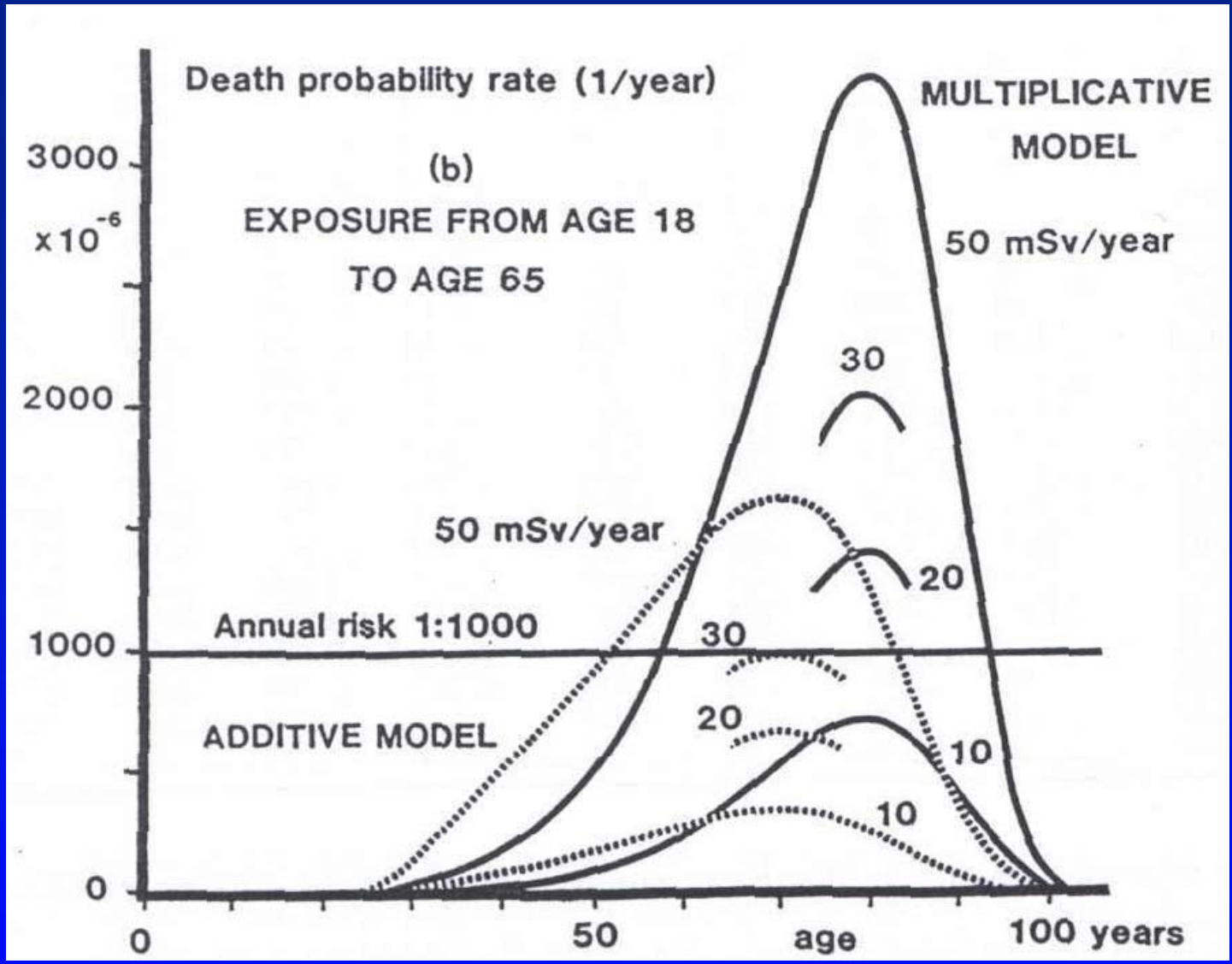


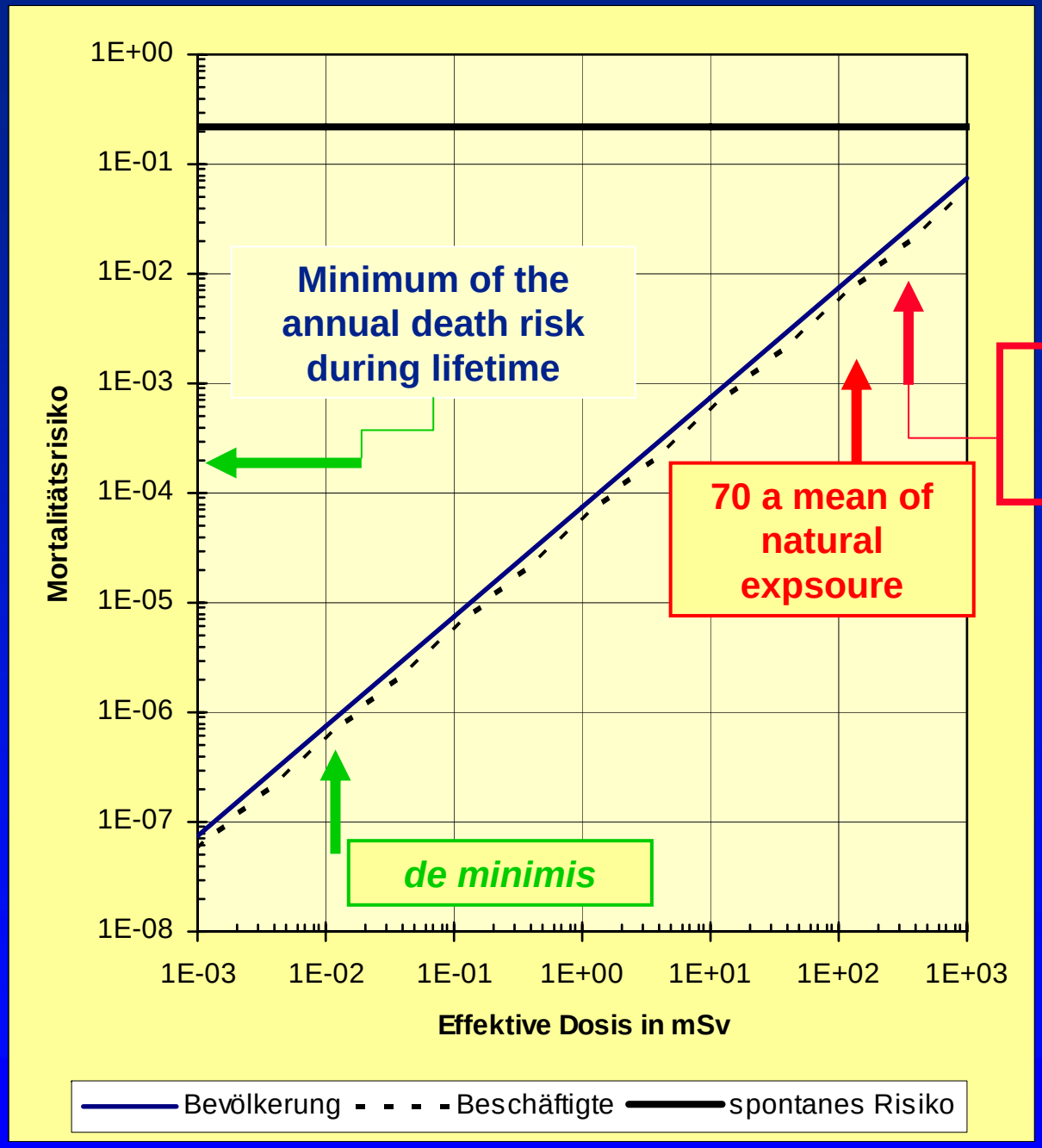
Fig. C-9. The unconditional death probability rate (the attributable probability density of the age of death, normalised for lifetime risk) for two exposure situations: (a) exposure from birth over lifetime, and (b) exposure from age 18 to age 65 years. *The curves are for females, assuming a DDREF of 2.*

Nominal Probability Coefficients of Stochastic Radiation Effects

exposed population	Risk according to end point in 10^{-2} Sv^{-1}			
	cancer fatal	cancer non-fatal	severe hereditary effects	total
adult „occupationally exposed population“	4,0	0,8	0,8	5,6
total Population, al age groups	5,0	1,0	1,3	7,3

ICRP 60 (1991)

Death risk due to cancer



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Radiation-Induced Mutations

- **GENE-MUTATION** (point mutation – chemical changes on DNA)

- **CHROMOSOME-MUTATION** (structural aberration)
  - Deletion (loss of a chromosome section)
  - Duplication (doubling of sections)
  - Inversion (tilt of a section by 180°)
  - Translocation (translocation of a section on a non-homologous chromosome)

- **ANEUPLOIDS** (numerical aberrations)
  - Monosomy (chromosome loss)
  - Trisomy (chromosome gain)

Natural Frequency of Genetic Defects

25 % of all premature aborts are induced by chromosome anomalies.

4 % of all pregnancies have an unfavorable abort due to chromosome anomalies.

2-3 % of life-born children have defects have defects induced by dominat mutations and chromosome anomalies.

ICRP 60 from animal experiments:
Risik of severe hereditary effects $1{,}3 * 10^{-2}\ Sv^{-1}$

The 15-Country Collaborative Study of Cancer Risk among Radiation Workers in the Nuclear Industry: Estimates of Radiation-Related Cancer Risks

A 15-Country collaborative cohort study was conducted to provide direct estimates of cancer risk following protracted low doses of ionizing radiation. Analyses included 407,391 nuclear industry workers monitored individually for external radiation and 5.2 million person-years of follow-up.

A significant association was seen between radiation dose and all-cause mortality:

excess relative risk per Sv (ERR/Sv) 0.42,
90% CI 0.07, 0.79; 18,993 deaths.

This was mainly attributable to a dose-related increase in all cancer mortality

ERR/Sv 0.97
90% CI 0.28,1.77; 5233 deaths.

The 15-Country Collaborative Study of Cancer Risk among Radiation Workers in the Nuclear Industry: Estimates of Radiation-Related Cancer Risks

Among 31 specific types of malignancies studied, a significant association was found for lung cancer

ERR/Sv 1.86, 90% CI 0.49, 3.63; 1457 deaths

and a borderline significant (P < 0.06) association for multiple myeloma

ERR/Sv 6.15, 90% CI < 0, 20.6; 83 deaths

and ill-defined and secondary cancers

ERR/Sv 1.96, 90% CI < 0.26, 5.90; 328 deaths.

Stratification on duration of employment had a large effect on the ERR/Sv, reflecting a strong healthy worker survivor effect in these cohorts. This is the largest analytical epidemiological study of the effects of low-dose protracted exposures to ionizing radiation to date. Further studies will be important to better assess the role of tobacco and other occupational exposures in our risk estimates.

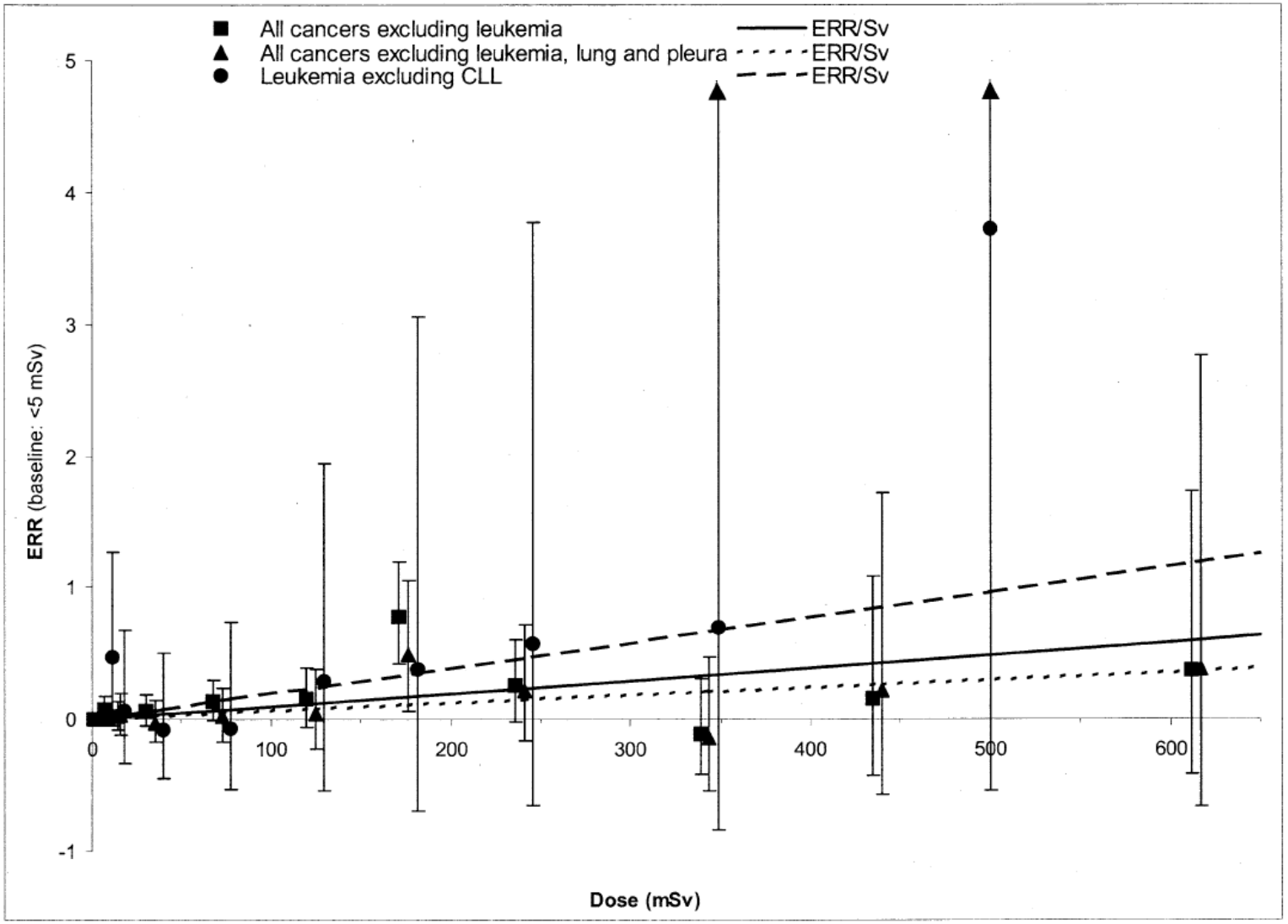

FIG. 1. Excess relative risk by dose category (relative to <5 mSv category) and 90% CI: all cancers excluding leukemia, all cancers excluding leukemia, lung and pleural cancers; leukemia excluding CLL. For leukemia excluding CLL, the 400–500 and >500 mSv categories have been combined because these two categories had very extreme values, based on very small numbers of death. In the combined >400 mSv category, the ERR/Sv was 3.73 (90% CI −0.54, 20.9).

Cardis et al., Radiation Research 167 (2007) 396 - 416

Radon in Homes and Lung Cancer

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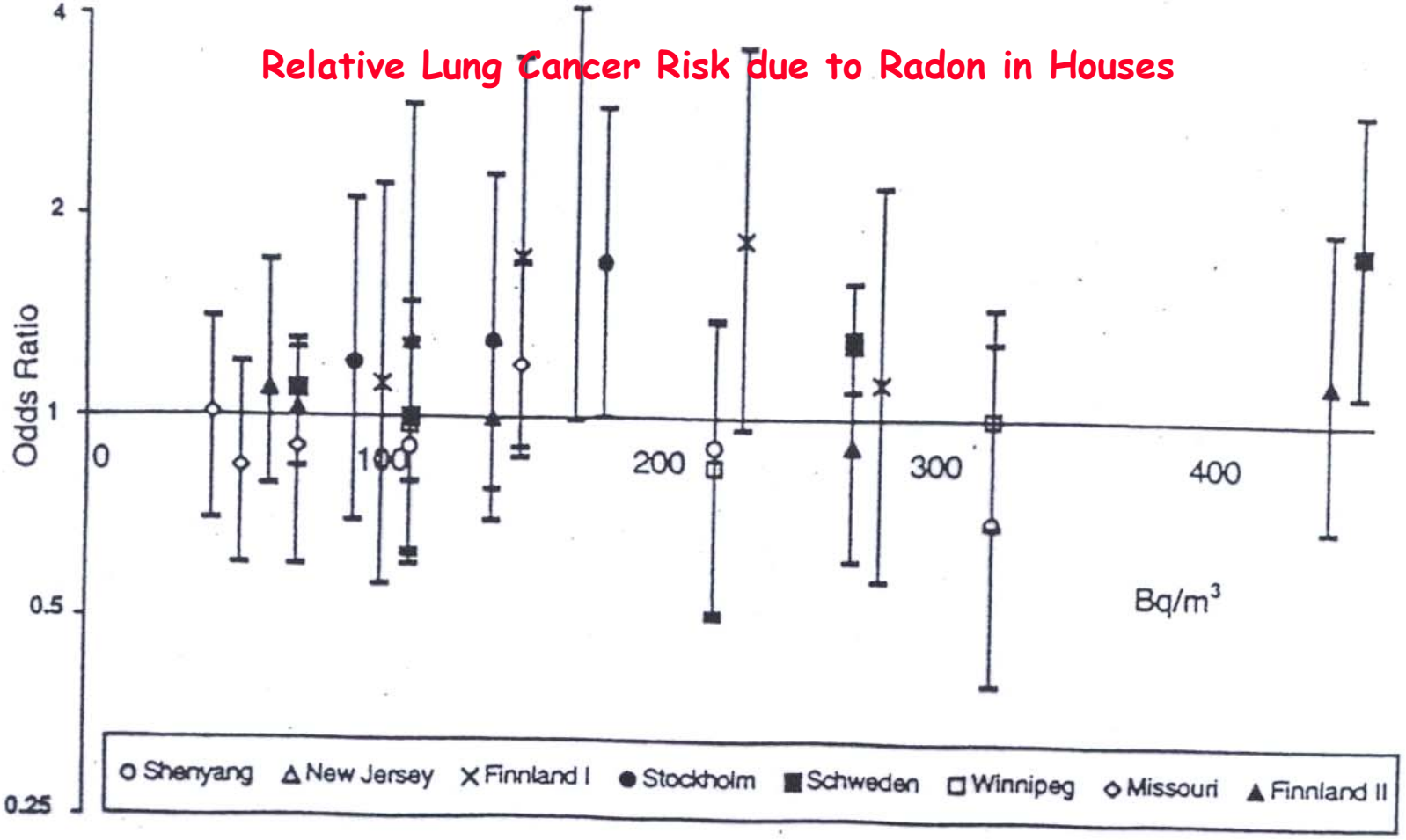
Relative Lung Cancer Risk due to Radon in Houses



Relatives Lungenkrebsrisiko durch Radon in Innenräumen, Zusammenfassung der Ergebnisse bisher publizierter Studien, Quellen: Shenyang: Blot et al. (1990), New Jersey: Schoenberg et al. (1990), Finnland I: Ruosteenoja (1991) bzw. Ruosteenoja et al. (1996), Stockholm: Pershagen et al. (1992), Schweden: Pershagen et al. (1994), Winnipeg: Létourneau et al. (1994), Missouri: Alavanja et al. (1994), Finnland II: Auvinen et al. (1996)

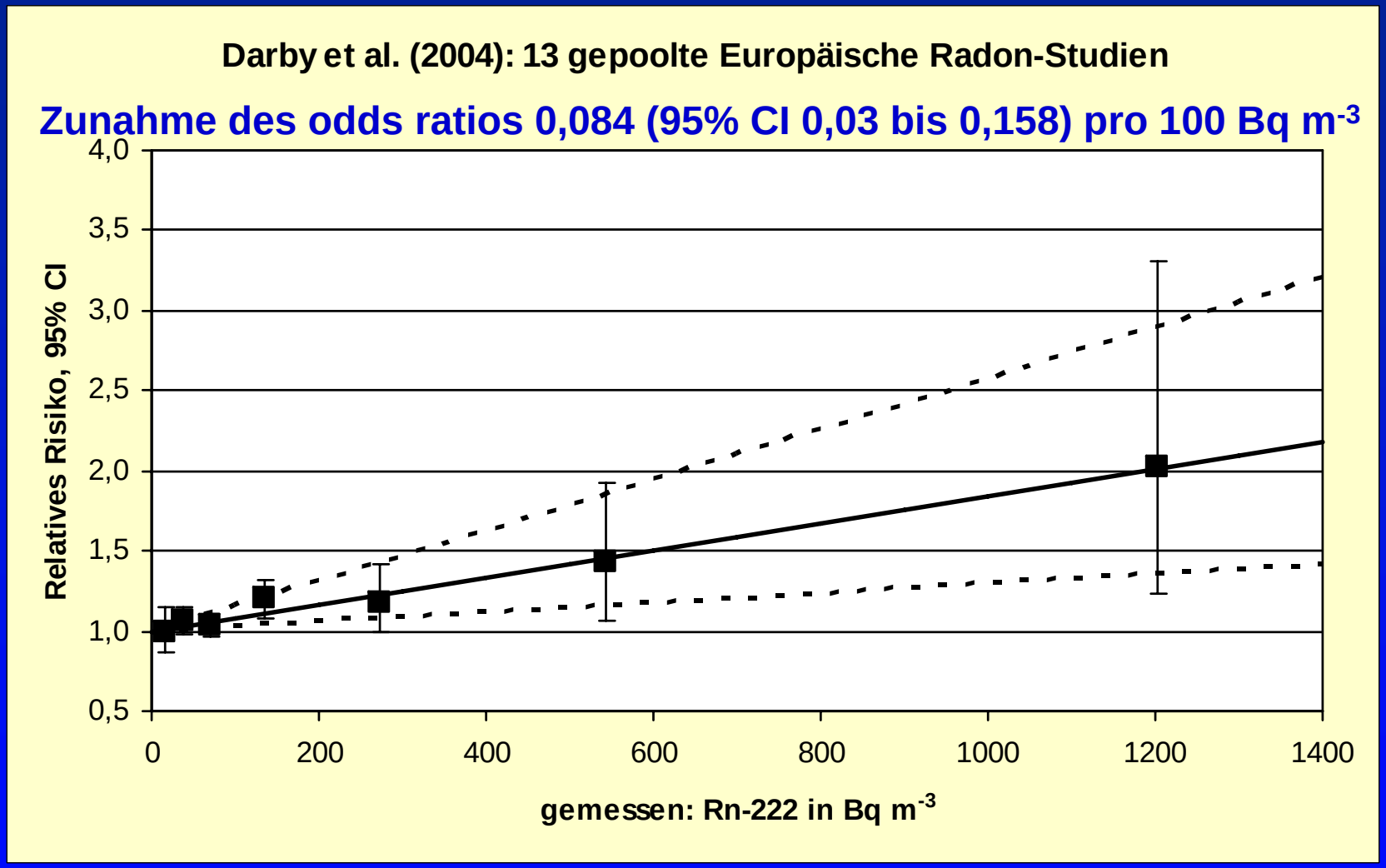
Wichmann et al. (1997)

Radon in Homes and Risk of Lung-cancer: Collaborative Analysis of Individual Data from 13 European Case-Control Studies

S. Darby et al., BMJ, doi:10.1136/bmj.38308.477650.63 Published 21.12.2004

measured Radon in Bq m^{-3}			relative risk			number of	
lower	upper	mean	value	lower 95 % CI	upper 95% CI	cancer cases	controls
0	25	17	1	0,87	1,15	566	1474
25	49	39	1,06	0,98	1,15	1999	3905
50	99	71	1,03	0,96	1,1	2618	5033
100	199	136	1,2	1,08	1,32	1296	2247
200	399	273	1,18	0,99	1,42	434	936
400	799	542	1,43	1,06	1,92	169	498
> 800		1204	2,02	1,24	3,31	66	115
						7148	14208

Radon in Homes and Risk of Lung-cancer: Collaborative Analysis of Individual Data from 13 European Case-Control Studies



S. Darby et al., BMJ, doi:10.1136/bmj.38308.477650.63
Published 21.12.2004

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If the risk of lung cancer increases by about 11 % per 100 Bq/m³ usual radon the cumulative absolute risks of lung cancer by age 75 years would be

Radon in Bq m^{-3}	0	100	400	800
cigarette smokers	10,1 %	11,2 %	14,5 %	19,0 %
lifelong non-smokers	0,41 %	0,46 %	0,59 %	0,77 %

S. Darby et al., BMJ, doi:10.1136/bmj.38308.477650.63
Published 21.12.2004

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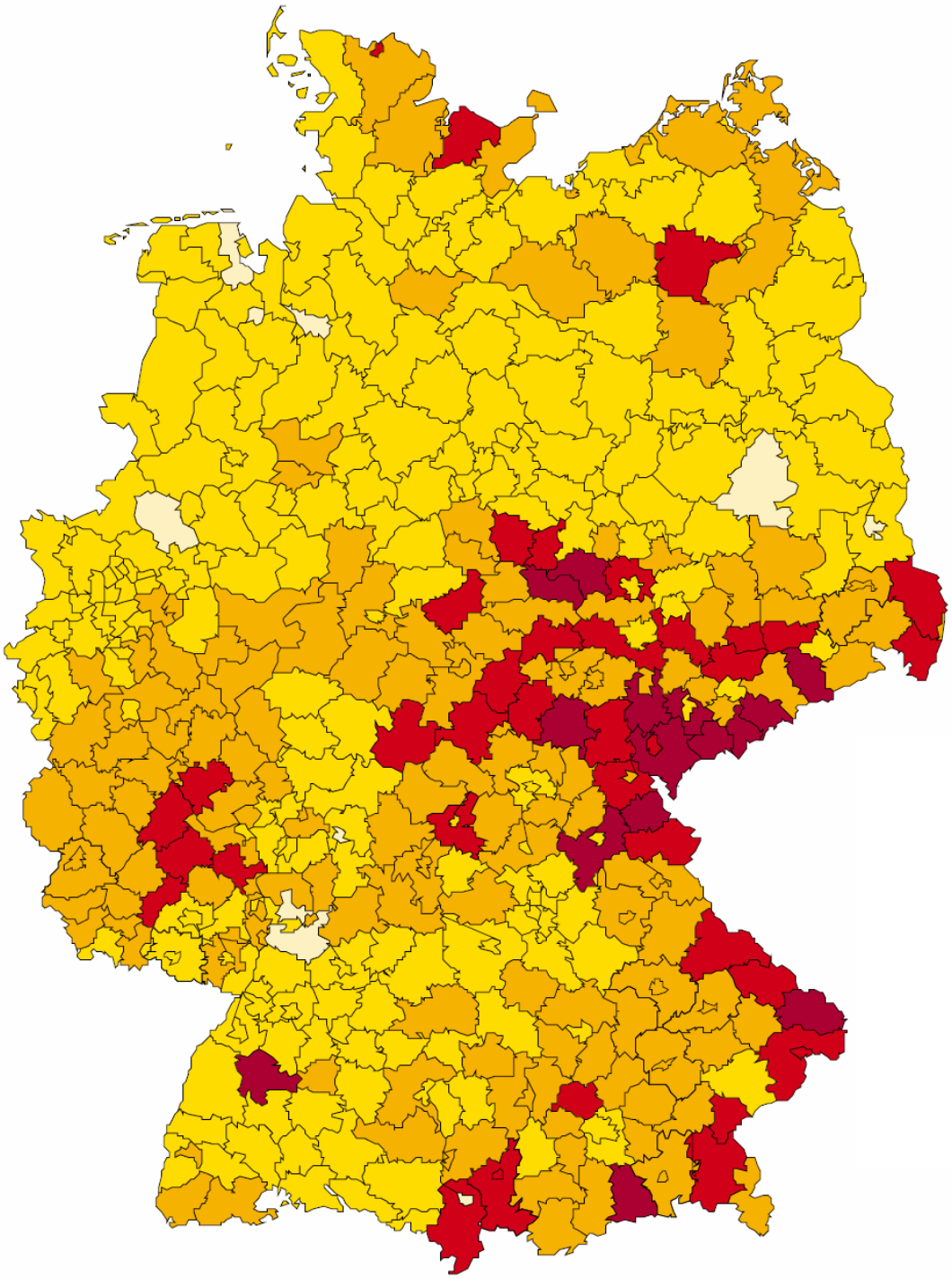
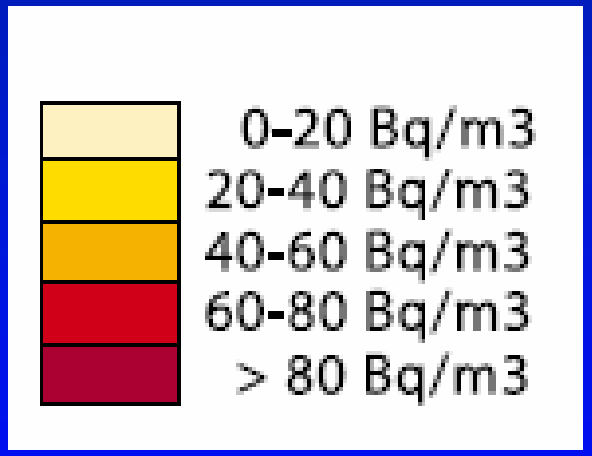


Mean Radon Concentrations in Dwellings in Germany



Brüske-Hohlfeld, Kreienbock, Wichmann, mensch+umwelt spezial 18. Ausgabe 2006, 37

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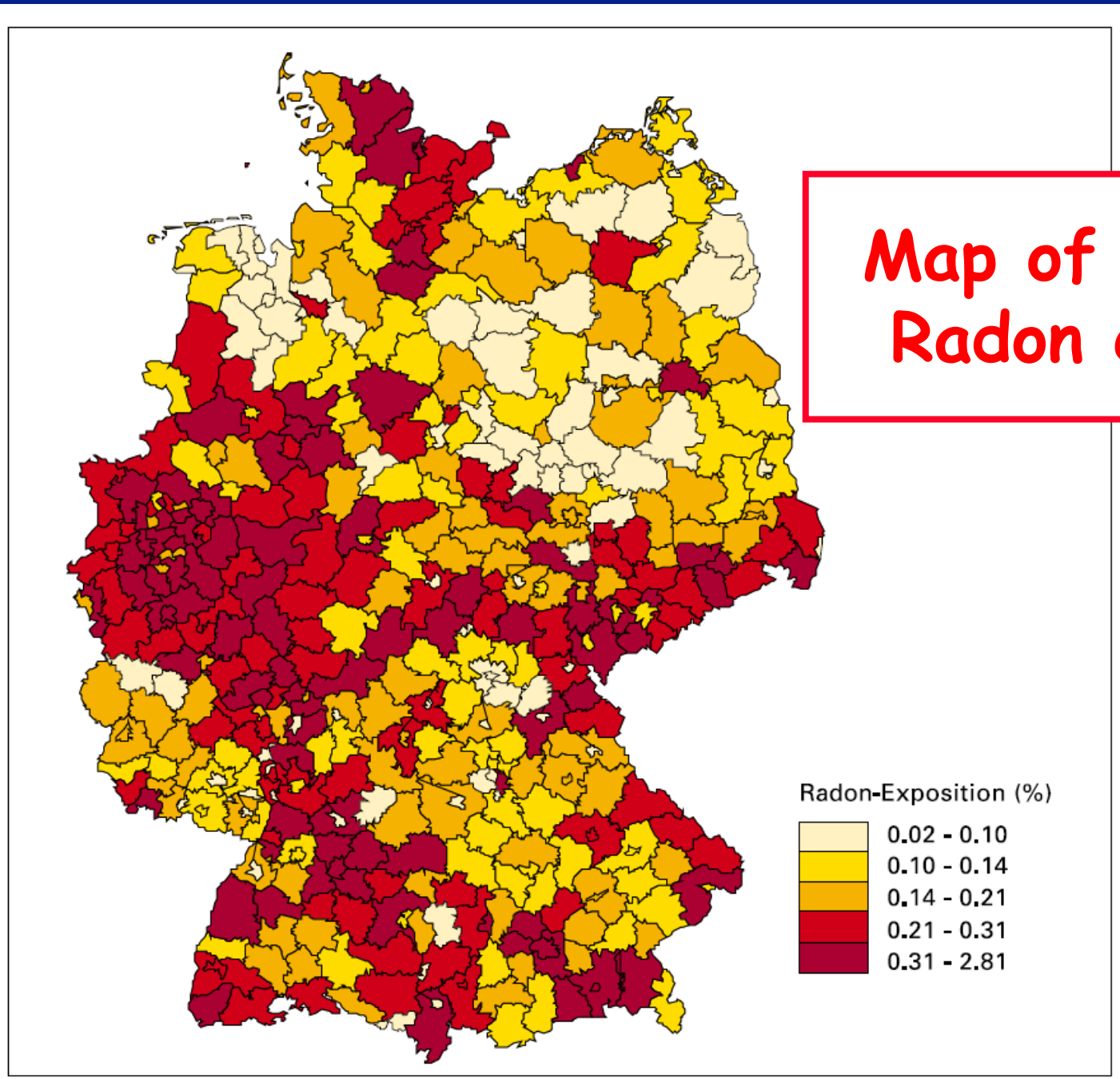

Map of collective Radon exposure

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Avoidable Number of lung Cancer Deaths per Year in Germany by Limitation of the Radon Exposure

Maximum value in Bq m^{-3}	Number of avoidable lung cancer deaths
9 (ambient air)	1896
100	302
200	143
400	68
1000	20

(aus Menzler et al 2006)

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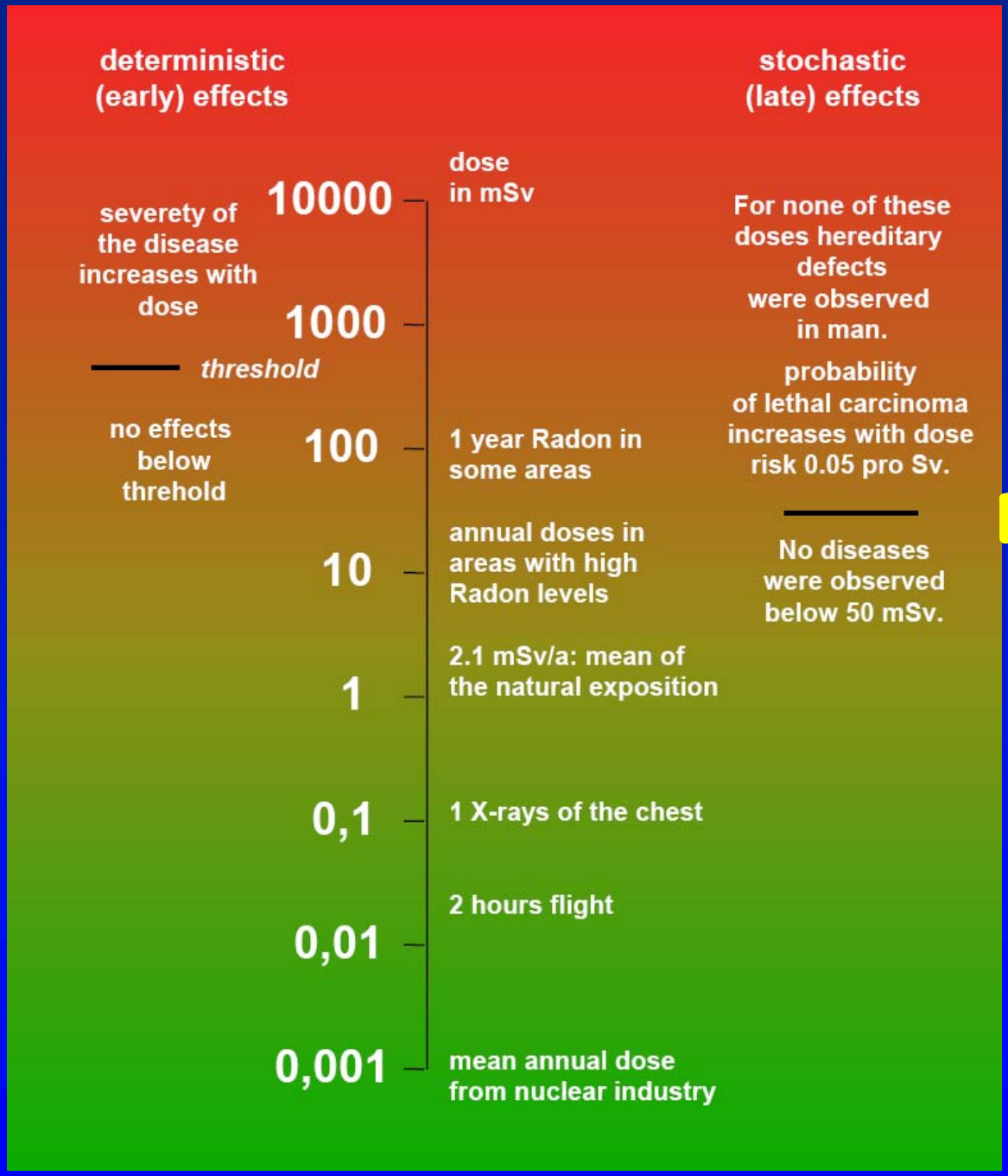
Biological Effects of Ionizing Radiation and the Radiation Exposure of Man



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